M. de Lesseps

THE

INDUSTRIES OF THE WORLD

A COMPLETE COURSE OF

TECHNICAL EDUCATION

FOR THE

MANUFACTURER, OPERATIVE,

AND

ALL PERSONS ENGAGED OR INTERESTED IN TRADE AND COMMERCE.

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CHAPTER I.

TEXTILE MANUFACTURES—COTTON, FLAX, SILK, AND WOOL.

IT will be unnecessary to urge on the reader the great importance which textile manufacturers possess in regard to this country. In one respect they differ from our metal manufacturers, for the raw materials of these are abundant with us. But in regard to our textile products, most of the raw material has to be imported from other countries; in the case of cotton and silk, entirely so. And in regard to wool, flax, and similar articles, our growth of them furnishes but a small contingent for our manufacturers. Yet, owing to the perfection of our machinery, we can bear the expense that foreign production imposes on our imports, and, indeed, more than that, we can actually import from India cotton, &c., and return it manufactured, as exports to that country, where we can sell them at a very remunerative profit under ordinary circumstances. Similar remarks also apply in regard to our woollen and flax manufactures, but to a more limited extent.

Into the general history of the manufactures of clothing material and clothing, we need not here enter. In the first volume the Introduction gives ample details of the subject at from p. xxxi. to p. xlii. At pp. xxxiv. and xxxv., a glance is given at the localities wherein our most important textile manufactures are carried on, and the early history of the machinery employed is also afforded with illustrations. At p. xxxix., *et seq.*, a brief description is given of the varieties of cotton used for spinning purposes, and the comparative characters of the fibres of flax, cotton, wool, and silk, are illustrated by Fig. 31, p. xlii. In some respects, therefore, it will not be necessary to go over this ground again, except when more minute details are desirable to elucidate our subject. But it may be desirable here to give a kind of general outline of the various processes through which fibrous material has to pass before it becomes converted into forms useful for the purposes of man.

FIBRES AND OTHER MATERIALS OF TEXTILE FABRICS, ETC.

Almost every species of plant—from the tall palm of the tropics to the flax plant in our own country—has been employed in producing some kind of fibrous material; hence the variety which presents itself to our notice will demand that we should devote a considerable space to their description. A table, which will be subsequently given, affords the names, qualities, and uses of some of the most important, many of which we shall, however, deal with individually at greater length.

Almost every part of plants affords fibre of some kind, as would be naturally expected from their constitution; but each specific fibre is produced only from one portion of the plant. Thus, cotton is really the fruit of the cotton shrub; whilst flax, hemp, &c., are produced from the stem of the plant affording them. Some fibres are obtained from the leaves, as those of the pine-apple, plantain, &c. Coir-fibre is contained in the external husk or epicarp of the cocoa-nut; the bark of the lime and other tribes affords a similar material. Again, almost the whole of many grasses are fibrous; the roots, however, as with all other plants, forming the exception; for that part is usually too dense and intractable to afford any material which can be manufactured into fabrics of any kind. The lowest class of plants, the *Cryptogamia*, rarely possess any substance of value as fibre; but they are useful as affording dyes of various kinds, especially the lichens and mosses.

The fibre is removed in a variety of ways, depending on the character of the plant from which it is obtained. Cotton has simply to be gathered from the pod; whilst almost every fibre obtained from the stem of plants must be separated by a rotting or mechanical process. If the former method be adopted, as in the case of flax, &c., the stem is immersed in ponds or other suitable receptacles filled with water, and left to soak for a fortnight, or longer, depending on the temperature of the atmosphere. By this means a kind of putrefactive fermentation is induced, through which the fibre and woody matter of the plant become separated. This separation is completed by exposure to the sun and air, during a partial drying, and by subsequent combing, &c.; if proper care be taken, the fibre is thus produced in a form suitable for the manufacturer. Many precautions, however, are necessary; for, if the process be carried too far, the strength of the fibre will be injured; whilst, if not sufficiently effected, a large amount of woody matter is retained, which greatly deteriorates the quality of both the yarn and cloth manufactured from the flax, &c.

When mechanical means are alone employed, the stem is broken or crushed by suitable machinery, and the fibre cleansed from the woody matter by a kind of combing process. By this method no danger is incurred of rotting or weakening the material; although, of course, it must be somewhat injured by the violence employed in detaching it from the stem of the plant.

The fineness of vegetable fibre varies exceedingly, as might be expected, from the numerous and varying sources whence it is obtained. Some specimens have been already figured in the Introduction at page xlii., Fig. 31, which will give an idea of the diversity of the finer sort. The gradation is extensive, as shown in the difference between cotton, flax, hemp, jute, coir or cocoa-nut fibre, and the piassaba, which is too coarse to be dealt with by machinery. In each species the fineness and length also vary. Thus, in cotton, there are the short, coarse Surat and Madras; the finer and longer-stapled American; and the still finer Sea Island and Egyptian varieties. Generally speaking, taking the *whole* of the fibrous productions of plants, fine and short staple, and long and coarse, are respectively associated—most long fibres being strong and wiry; whilst those which are short are delicate, silky, and very attenuated. The size of woody fibre ranges from about the $\frac{1}{100}$th to the $\frac{1}{3000}$th of an inch in diameter; and in determining the proper thickness of any kind, care must be taken that the single fibre, and not that in bundles, be judged from: the latter condition is the most common with almost every species, as may be noticed in many kinds of flax and hemp.

The strength of fibre also varies greatly, and it does not invariably depend on the relative fineness; for, as is noticed in iron columns, that those which are hollow are stronger than others of the same diameter, but solid, so, in vegetable matter, a fibre is generally weakened when its hollow tube is filled up. New Zealand flax—the *Phormium tenax*—is an instance of this kind; for, as its name implies, it is tenacious enough when pulled lengthways; yet, if bent double, it is very brittle, and readily snaps asunder.

Generally speaking, fibre is prepared for domestic purposes by the process of spinning. This consists of twisting fibres round each other by proper machinery; so that, by uniting a number together, any amount of strength may be obtained. The preparatory process is that of placing all the fibres in a parallel direction, and this is effected by means of carding. The carding-engine is formed of rollers, coated with short metallic wires: these rollers revolve parallel to and over each other, the space between them being occupied by the material. As the fibres pass through the engine, they are arranged side by side (the number and thickness depending on the size of the thread to be formed, and passing out at the other end of the machine, in the form of a "sliver"); and, like a ribbon, they are carried in cans to the slubbing or spinning-frame. Before entering the "carder," the operations of "scutching," &c., are performed; the object of which is to clear the fibre of extraneous matter, and, in part, to prepare it for the carding process.

The essential parts of a spinning-frame, employed for producing any kind of yarn, are readily explained. The fibres of the material are supposed to be laid in a parallel direction by the carding process, in the form of the "sliver" just named. The end of one of these slivers is introduced between a pair of rollers, forming the back of the spinning-frame, and the sliver gradually passes in, and is caught by another pair. These extend the length of the sliver, and diminish its width. Another pair of rollers, in front of them, still more attenuate the sliver, and, at last, the spindle is reached, through eyes in the "flyer" of which the "roving" (as the thick thread is called) passes. The flyer and spindle revolve rapidly, and, by a peculiar arrangement, simultaneously twist the roving, and wind it on a bobbin, where it arrives in the form of "yarn." This yarn is of different thicknesses, according to the fineness of fibre, the degree of "drawing," and the amount of twist which has been employed.

From the bobbin, the yarn, after dressing, warping, &c., is conveyed to the weaving loom, where, by means of proper machinery, it is laid in directions at right angles to each other; that is, one yarn is placed breadthways, and another lengthways, of the cloth—the latter being termed the "warp," and the former the "woof," or "weft." A close material, of any length, is thus obtained—termed, generally, "cloth," and corresponding with the calicoes, so called when it is made of cotton.

The subsequent processes of bleaching and dyeing are purely ornamental, and matters of taste, which vary with the fashion, &c. In respect to the stimulus which recent discoveries in chemistry have given to this branch of manufacture, it is impossible for us to give an adequate idea; but it may suffice to say that, eighty years ago, a good "print" cotton gown-piece cost from thirty to fifty shillings; whilst, at the present day, such is sold for about as many pence. So great has been the advance of our manufacturing industry during a comparatively short period.

The preceding remarks are intended to give only a very bare outline of the different processes through which fibrous materials pass from the raw state to that in which they are fit for the use of man. The details of these processes will come more fully under review as we examine each article separately; our object for the present being simply to give such a general description to the reader as may enable him to form a connecting link between the production of the raw material and the uses to which it is applied in daily life, when manufactured. It is remarkable how early man became acquainted with the nature and properties of many of these fibres, and how complete were several of the ancient processes. In many, indeed, the moderns have made no progress, so far as principle is concerned; whilst, in others, we have simply modified, but not invented. The chief cause of the progress which has been made in Great Britain, in manufacturing, has been the abundant supplies of coal and iron which our mines afford—sources of wealth before which all the gold, silver, and precious stones that have yet been brought to light, sink into comparative insignificance.

It has been found that considerable difficulty exists in attempting to spin together fibres of

different materials, owing to certain peculiarities of structure. During the American civil war, many inventions were revived, or brought out fresh before public notice, having for their object the preparation of fine fibre from flax, hemp, jute, &c., by chemical means, which might be employed as a substitute for cotton. In 1849-'50 we succeeded in this respect; but then found, on trying it on the large scale, that the hempen fibre is far too brittle to undergo the processes involved in cotton-spinning; and this fact soon became evident to all who tried the inventions to which we have alluded. The fibre breaks off so short as to cause a great proportion of the quantity used to fall down, both in the carding and spinning operations, almost as dust, and hence the waste is enormously great; for this reason the schemes were all speedily abandoned. Flax, hemp, and jute, may all, however, be spun individually or with long-stapled articles; and hence they are frequently mixed with wool and silk, especially with the latter. Another objection to the admixture of cotton, wool, and silk is, that there is no "life" in the cloth produced: or, in other words, it has much less elasticity than that manufactured from those materials alone.

Amongst the important uses to which fibre is applied, is that of the paper manufacture; and, for this purpose, rags, obtained from worn-out cloth, either linen or cotton, are mostly employed. It has been found much more economical to use the material in this form than in the fibre as obtained directly from the plant; for, in the latter case, much labour and expense is incurred to reduce it to pulp, owing to its length and rigidity. The rags, on the other hand, present the fibrous substances in much shorter staple, and are, therefore, more readily convertible to the purposes of the paper manufacturer. Owing, however, to the scarcity of rags, many attempts have been made to discover a suitable and cheap material, and great pecuniary inducements have been held out, in this respect, to the ingenuity of scientific and practical men. Grasses, but especially straw, woody fibre from the elm, sugar-cane, and numerous other plants, have been used; but the most general substitute employed at the present day is the straw of Esparto grass, and the manufacture of paper from that material has now become both extensive and important. Most of the low-priced daily London and provincial journals are now printed on such paper.

The manufacture of any kind of paper depends on the conversion of the material into an extremely minute state of division, and in "felting" or uniting it by mechanical means, so as to present an even and non-absorbent surface, if intented for writing purposes. The following presents a general outline of the process, minor details being omitted.

The rags are first sorted by women, who also cut them to an even size, if such be required; and great care is taken that no woollen material enters amongst the rags intended for white paper, to which we shall confine our attention. The rags are then placed in a dusting machine, in which, by violent mechanical action, the loose dust and dirt are removed. The next process is that of washing; and, at the same time, by iron bars fixed on a roller revolving rapidly in a trough of water, which is constantly being renewed, the rags are torn to pieces, and converted into a kind of coarse pulp. This pulp is afterwards removed and bleached in a chamber, by means of chlorine, when the whole is converted into a perfectly white mass. This is then carefully washed; and, in another vessel, by means of cylinders revolving very rapidly, and coated with knives, the pulp is still further comminuted, becoming, with the water with which it is mixed, just like milk in appearance. At this stage the size is added, which afterwards prevents the absorption of writing-ink; for, without this, the pulp would simply produce an article exactly like, in fact constituting, ordinary blotting-paper. In some papers the colouring-matter is also added at this stage. The pulp is now introduced into a large vat, where it is kept in constant motion by means of a revolving roller and arms. From this vat the pulp passes into a square trough, which is always kept filled exactly to the same height; for on that being carefully attended to, depends the evenness of the sheet of paper produced. Next, beyond the trough is a wire frame, on to which the pulp flows and spreads in an even sheet. This frame is kept constantly in a jerking, horizontal motion, so as to spread evenly the fibre of the pulp on its surface, and to drain off through the wires a greater part of its contained water. The fibre gradually attains a consistency, which is increased by pressure of rollers covered with felt. These remove a still further portion of the water, and the paper, wet, then arrives at large cylinders, filled with steam, by which it is dried, and acquires a glossy surface. At last it reaches a roller by which it is wound up in one continuing, increasing, and never-broken sheet.

This manufacture is one of the most interesting and beautiful of any carried on by man; and the spectator cannot help feeling the greatest astonishment at perceiving a thin fluid, apparently like milk when entering one end of the machine, converted, in the space of a few minutes, into a tenacious and beautifully even sheet of paper. During the manufacture, a curious phenomenon may sometimes be observed; it is that of the production of free electricity. We have frequently noticed sparks, of from two to six inches long, given off from the surface of the web; and this result is sometimes a source of much discomfort to the workman—raising the hair of his head, and occasionally giving him a shock.

In former times, paper was chiefly produced by hand, at the rate of a sheet at a time; the size, which was generally small, depending on that of the machine; and this plan is still adopted for many kinds of paper, but especially for Bank of England notes. These are made in a sheet affording two only, so that each has but one cut edge. The principles of the hand-process are identical with those just described,

as adopted in the machine; and the great advantages of the latter consist in its speed, even quality of production, and the unlimited length, in one web, which it affords: in fact, if the machine be properly supplied with material, the process may, and often is, carried on without a single stoppage, night and day, for weeks together.

The coarser kinds of paper, as brown, packing, &c., are manufactured in a similar manner. For these, however, coarser materials are employed, such as old bags, ropes, and the like. Of late years, numerous applications of paper have been suggested—not one of the least curious being that of pipes for conveying water. The *papier maché* affords a material largely used for making ornamental articles. Indeed, we are far behindhand, in Europe, in employing paper for purposes of utility. In China, where it is supposed that the paper manufacture was known about 2,000 years ago, its uses are almost innumerable. Paper must not, however, be confounded with what is called "Rice-paper," once so largely exported from that country. This is obtained from a tree growing in Formosa, of the Ivy order (*Araliaceæ*), the *Aralia papyrifera:* the pith is cut into sheets of extreme thinness by means of large knives, and is then packed in squares of about three inches each way. It is a beautiful material, largely employed for making ornaments, artificial flowers, &c.; and is also painted on by the Chinese, who sell it at the rate of about 1½*d*. per 100 squares. The principle of paper-making has also been adapted to the production of carpets; felt, for covering boilers, roofs, &c., and many analogous objects. In this, as with perhaps every other branch of industry, the removal of all fiscal restrictions has caused a great expansion, alike beneficial to the commerce of the country, as it will undoubtedly prove promotive of its moral and mental advancement. The enormous variety which we have already alluded to as known, in respect to the fibre afforded by plants, and the probability of fresh sources continually springing up, give hopes that, at no distant date, a much more abundant and suitable supply of raw material will be afforded than even we now possess. Such would materially tend to lessen the cost of all literary productions, and render the spread of knowledge easy, and less costly. No country in the world is more indebted to the press than is our own; and, however important other objects may, and must be, yet a cheap means of diffusing literature and science, cannot but be regarded as of the highest value; and, as providing food for the mind, second only to that provision which our bodily wants compel us to insure. It has been well and tersely said—"Knowledge is power:" and the moral power which we, as a nation, exercise throughout the globe, has resulted from a mental cultivation that has itself been chiefly due to the productions of the steam-engine, the printing-press, and the paper-making machine—inventions which may therefore rank as the most valuable in the possession of man.

In a future table of raw products, many substances are included which barely deserve the name of fibre, or which, perhaps more correctly, are not usually reduced to a fibrous state before being converted into articles of utility, although, in some instances, they are capable of being so treated. Of this kind are the various barks, which are often used as they are taken from the tree. The *Daphne papyracea* and *Edgeworthia gardneri* are largely employed in India for the manufacture of all kinds of paper, which is afforded from the fibrous bark. The paper much resembles our own, but seems more porous; it is strong and durable, and is said to be very suitable for the purposes of the engraver. The Lace-bark, from the *Lagetta lintearia*, is a beautiful natural production of the bark of the tree, and exactly resembles the finer kinds of lace. The fibre undergoes no spinning or other mechanical process, but is employed as cut from the tree, to make caps, bonnets, collars, slippers, purses, ropes, whips, baskets, &c. Somewhat resembling these, but very much coarser, are the Cuba and Lime basts, which are familiarly known as used, the former for tying up cigar-bundles, and the latter for gardening purposes, making mats, &c.

The Mulberry order affords some bark-fibres, which are convertible to many useful purposes. The Paper Mulberry (*Broussonetia papyrifera*) is converted, by the Polynesian islanders, into paper and Tapa cloth. The bark is beaten out by mallets made of hard wood, and scraped by shells to make it smooth, by which a cloth is made that is used for garments of various kinds. From the Black Mulberry (*Morus nigra*) the Chinese also fabricate a coarse kind of cloth. The Namagua bark—obtained from the *Brosimum namagua*, a native of Grenada, and the northern parts of South America—is generally used as a material for beds; and, doubtless, its fibre might be converted to numerous other useful purposes.

The Palm order, *Palmaceæ*, affords a great variety of useful fibres. The Cocoa-nut palm, for instance, is especially valuable, its external husk affording a fibre converted into ropes, nets, yarn, mats, &c., and generally known and imported as "coir:" in Scotland, we have frequently noticed slices of the husk used as scrubbing-brushes, for which purpose it seems admirably suited. The leaves of the date, and many other palms, are woven into baskets, hammocks, caps, bags, fans, umbrellas, tent-covers, &c. Some, as the *Ita*, *Ruffia*, &c., give good thread, the latter being woven by the natives of Madagascar, to make what is called Malagasy cloth—an article of universal employment for garments.

The Grass tribe (*Gramineæ*) abounds with materials from which excellent fibre is producible. The Esparto, or Sparto grass, affords an excellent fibre for the paper manufacturer, for which, as already stated, it has been extensively used. The straw of the cereals is also a most important material for paper-making, besides affording the plait so familiar in the straw bonnets and hats; the sugar-canes are useful, when properly prepared, for the same objects.

Most of the orders which produce fibres resembling hemp and flax, we shall more particularly refer to when we describe the manufacture of those materials ; and similarly, cotton will deserve a more detailed examination.

The rushes, sedges, canes, and, perhaps, the Piassaba fibre (which is much like split cane, and forms the material of our garden brooms), are all unfitted for manufacturing, the former, indeed, scarcely containing any fibre at all. In the same category fall the willow and osiers : but these have their separate and often essential uses. Thus the rushes, sedges, and osiers are made into baskets, beehives, hammocks, mats, &c. The willow affords also plait for bonnets : and some kinds of rush, especially the Lancashire variety, are used in the manufacture of the well-known "rush-light." That most curious of all known plants, the Cactus, furnishes material from its stem out of which many ornamental and fancy articles have been fashioned. Some species, it will be remembered, are invaluable, as affording food to the cochineal insect, so largely used as a material for dyeing silk, &c., of a red colour. It may be curious here to notice, that from two to three million pounds of this insect are annually imported into this country, and it requires about 70,000 of them to make one pound in weight of the dye-material.

Allusion has been already made to the ingenuity which savages apply to the preparation of fibre for useful purposes. The following, giving a particular description of a method only just briefly hinted at, will afford an illustration of this fact.

The Otaheitans make cloth of the bark of the paper mulberry-tree. The material from another kind, inferior to the first in whiteness and softness, is obtained from the bread-fruit tree. A third sort is made from a plant resembling a fig-tree ; this is coarse and harsh, and of the colour of the darkest brown paper. Although apparently of an inferior description, it has a quality which renders it much more valuable in use than the others ; namely, its resistance to water, in which the other two are deficient. In preparing the materials for these kinds of cloth, the bark is not merely stripped off the trees as they grow in wild luxuriance, but the trees are carefully cultivated for the purpose of producing good and even bark. The lower leaves with their germs are taken off wherever they give any indication of producing a branch ; as it constitutes the excellence of the trees to be thin, straight, tall, and without lower branches. The proper time for using them is when they are about six or eight feet high, and somewhat more than an inch in diameter. The plants are then drawn out of the ground, and stripped of their leaves and branches ; after which the roots and top are cut off, and the bark, being slit longitudinally, is readily separated from the stem. It is then placed in running water, and secured in this situation by placing heavy stones upon it. When sufficiently macerated, the inner bark is separated from the green outer rind. In performing this operation the women sit in the water, and placing the bark on a smooth board, scrape it with a shell : the fibres are found to separate more readily when immersed in water while being scraped ; and the useless parts are washed away at the moment of their disengagement. This work is continued until nothing remains but the fine fibres of the inner coat.

The fibres thus prepared, they are worked up into a kind of cloth in a peculiar manner. The cleaned fibres are spread out on plantain leaves to the length of about eleven or twelve yards ; these are placed on a regular and equal surface of about a foot in breadth. Two or three layers are thus placed one upon the other, much attention being paid to the equable arrangement of the whole. If in any one of the layers the bark happen to be thinner in one particular spot than another, a piece somewhat thicker is laid over that part in the next layer. This being completed, the united layer is left to dry during the night, when, great part of the moisture with which it had been saturated having evaporated, the several layers are found to adhere together, so as to allow of the whole being raised from the ground in one piece. It is then laid on a large smooth plank of wood prepared for the purpose, and beaten with a wooden instrument about a foot long by three inches square ; each of the four sides of the instrument has longitudinal grooves of different degrees of fineness, the depth and width of those on one side being sufficient to receive a small packthread, the other sides being finer in a regular gradation ; so that the grooves of the last side would scarcely admit anything coarser than sewing-silk. A large bundle being attached to this instrument, the cloth is beaten first with its coarsest side, and spreads very fast under its strokes ; it is, after this, beaten with the other sides successively, and then is considered fit for use as cloth. Sometimes, however, it is made still thinner by beating it, after it has been several times doubled, with the finest side of the mallet ; and it thus will be attenuated to such a degree as to be very little thicker than muslin. The cloth will sometimes break while under this rough process ; but the fracture is very readily repaired by applying a piece of the bark, which is made to adhere by a glutinous substance prepared from the root of one of these plants. The cloth prepared in this very curious manner, especially when made from the bark of the mulberry-tree, becomes extremely white by bleaching, so as to be durable, and to have a very good appearance.

The following table will afford at a glance some of the most interesting facts relating to vegetable fibres best known. It gives the ordinary name, the botanical name of the genus and species of the plant by which the fibre is produced, the botanical order or family according to the natural system, the native place or country where chiefly grown, and lastly, the chief qualities and uses. Specimens of all the fibres named may be seen in the Museum of Economic Botany, Kew, where, by the kind permission of the late Sir Joseph Hooker, F.R.S., &c., the Editor of this work collected by personal examination of each specimen the information which the table affords.

TABLE OF RAW PRODUCTS USED IN TEXTILE MANUFACTURES, Etc.

Name of Fibre, &c.	Botanical Name of the Genus and Species of the plant by which the Fibre is produced.	Order or Family.	Native Place, or where Chiefly Grown.	Qualities, Uses, &c.
Agave, or American Aloe	Agave americana	Amaryllidæ.	Mexico, &c.	Various fabrics are made from this and other species of Agave.
Amadou	Polyporus fomentarius.	Fungi.	Europe.	The source of "German tinder."
Bamboo	Bambusa arundinaceæ.	Gramineæ.	Tropics generally.	Paper, cloth, &c., of coarse kinds.
Banana	Musa sapientum.	Musaceæ.	Tropics generally.	Various fabrics; the fibre resembles flax.
Bast...	(See Cuba and Lime.)	——	——	Twine—Tying up cigar bundles, &c.
Bowstring Hemp ...	Sanseviera zeylanica.	Liliaceæ.	India.	Strong—Used for cordage, &c.
Cactus-fibre	Opuntia tuna, &c.	Cactaceæ.	Tropics.	From layers of the stem, baskets, ornamental work, &c.
China Grass, or Rhea	Bœhmeria nivea.	Urticaceæ.	China, India, &c.	Fine—Linens, cambrics, net, &c.
Cocoa-nut, or Coir	Cocos nucifera.	Palmaceæ.	Tropics generally.	Strong and coarse—Cordage, mats, brushes, bags, ropes, &c.
Cotton	Gossypium herbaceum, &c.	Malvaceæ.	Warm countries.	Length, strength, &c., of fibre, various. East Indian generally coarse and short; American finer and longer; Sea Island and Egyptian have the longest fibre.
Cotton (silk)	Bombax ceiba.	Bombaceæ.	South America.	A silky substance, unfit for spinning, but used for stuffing cushions, &c. Somewhat resembles thistledown.
Cuba Bast	Paritium elatum.	Malvaceæ.	Cuba, &c.	A bark—Used to tie up cigars.
Daphne	Daphne papyracea. Edgeworthia gardneri.	Thymelaceæ.	India.	Fibrous bark—Paper, resembling "whitey-brown," &c. Some very fine qualities used for writing purposes in N. W. India.
Date Palm	Phœnix dactylifera.	Palmaceæ.	North Africa and the deserts in the interior.	Plaited work, baskets, &c., from the leaves. Its fruit is the chief food of the natives of the Sahara and all Northern Africa.
Esparto Grass ...	Lygæum spartum.	Gramineæ.	Southern Europe, &c.	Coarse—Matting, cordage, baskets, paper, &c.
Fan Palm (Dwarf)	Chamærops humilis.	Palmaceæ.	Spain, Italy, and the Tropics generally.	Mats, baskets, caps, &c., from the leaves.
Flax	Linum usitatissimum.	Linaceæ.	Temperate Climes.	Varieties numerous—Yarn, linens, cambrics, &c.
Flax (New Zealand)	Phormium tenax.	Liliaceæ.	New Zealand, &c.	Strong—Cloth, baskets, cordage, &c.
Grasses	Very numerous.	Gramineæ.	Generally.	Some species, as wheat-straw, largely used for making paper: all afford fibre variously used; plait for bonnets, brushes, &c.
Grass-wrack	Zostera marina.	——	European sea-coasts.	A seaweed—used for making mattresses, packing, &c.
Gunny, or Jute ...	Corchorus capsularis.	Tiliaceæ.	India.	A coarse kind of jute—Used for making bags, matting, &c.
Hair Moss	Polytrichum.	Musci.	England, &c.	A moss—Used for stuffing cushions, &c.
Hemp	Cannabis sativa.	Cannabinaceæ.	Cool Climates, and also India.	In Europe, used for cordage, coarse cloth, &c.; in India, grown for the sake of its intoxicating properties, produced by a narcotic resin from the leaves and stem; and used in drinking, as Bhang, and in smoking, as Gunja. Oil of the seeds used for making soap.
Ita Palm...	Mauritia flexuosa.	Palmaceæ.	British Guiana.	Affords thread from leaves; baskets, fans, mats, &c., are also made from the leaves.
Ivy	Hedera helix.	Araliaceæ.	Temperate Climes.	Coarse—Rope, &c.
Jute	Corchorus capsularis.	Tiliaceæ.	India.	In India, for "gunny-bags;" in England, &c., used alone, or as an addition to, or substitute for hemp, flax, and silk.
Lace Bark	Lagetta lintearia.	Thymelaceæ.	Jamaica.	A bark resembling fine lace; and made into collars, sleeves, purses, &c.
Lime Bast	Tilia europæa.	Tiliaceæ.	Europe.	Affords the material of "Russia matting," &c.
Mallow	Malva (numerous).	Malvaceæ.	Generally.	The tribe comprises cotton, &c., and numerous other fibre-giving species.
Manila Hemp ...	Musa textilis.	Musaceæ.	Philippine Islands.	Various textile fabrics.

Maroot-fibre	Sanseviera zeylanica.	Liliaceæ.	Madras, &c.	Resembles, and is used as a substitute for flax.
Marsh Gladden ...	Scirpus lacustris.	Cyperaceæ.	British marshes, &c.	A sedge—Made into baskets, beehives, hassocks, &c.
Mulberry...	Morus nigra, &c.	Moraceæ.	China, &c.	The Chinese make a coarse cloth out of the bark.
Mulberry (Paper) ...	Broussonetia papyrifera.	Moraceæ.	Polynesia, &c.	The source of "Tapa" cloth, made by beating out the bark by mallets, &c.; resembles both hemp and paper.
Namagua Bark ...	Brosimum namagua.	Artocarpeæ.	Grenada, North of S. America, &c.	Resembles hemp—Made, as bark, into a kind of sacking, and used for beds.
Nettle-fibre	Urtica dioica, &c.	Urticaceæ.	Generally.	The Irish variety has been worked up into collars, and other fancy articles. The exotic species afford China grass (which see), cloth, cordage, &c. The fibres vary in length, and often may be used as substitutes for flax, hemp, &c.
New Zealand Flax	Phormium tenax.	Liliaceæ.	New Zealand, &c.	(See Flax.)
Neyanda-fibre ..	Sanseviera zeylanica.	Liliaceæ.	Ceylon.	Resembles, and is used as a substitute for flax.
Palm	Very numerous.	Palmaceæ.	Tropics generally.	Species very numerous, and all afford a fibre of some kind. Several are named in this Table, with their products.
Palmite	Juncus serratus.	Juncaceæ.	South Africa.	A rush—Used for plaiting, thatching, baskets, &c.
Palmyra Palm ...	Borassus flabelliformis.	Palmaceæ.	Tropical Asia.	Leaves made into mats, baskets, carpets, hats, umbrellas, &c. Its sap, when boiled down, affords, when fermented, an intoxicating liquor, called Toddy. The Jaggery, or palm-sugar, is obtained from it.
Paper Mulberry ..	Broussonetia papyrifera.	Moraceæ.	Fiji, &c.	(See Mulberry.)
Papyrus (Paper) ...	Cyperus.	Cyperaceæ.	Egypt, &c.	A kind of sedge, from which the ancient Egyptian paper was made.
Piassaba	Attalea funifera.	Palmaceæ.	Brazil, &c.	Coarse fibre—Made into brooms, ropes, &c.
Pine...	Pinus (various).	Coniferæ.	Europe, &c.	Coarse fibre—Fit for ropes, &c.
Pine...	Thuja gigantea.	Coniferæ.	N. W. America.	Bark affords a fibre resembling hemp—Baskets, hats, mats, wrappers, &c.
Pine-apple	Bromelia ananas.	Bromeliaceæ.	Tropics generally.	A fibre, suitable for fine articles, as muslin, cambrics, &c. Pita-fibre is obtained from some species of the *Bromelia*.
Pita-fibre...	Bromelia pita, &c.	Bromeliaceæ.	Tropics generally.	Resembles flax, for which it is an excellent substitute.
Plantain	Musa paradisiaca, &c.	Musaceæ.	Tropics generally.	Various fibres for cordage, &c. (See also Manila and Banana.)
Rattan-cane	Calamus rotang.	Palmaceæ.	Tropics generally.	When split, used for caning chairs, brooms, &c.
Rhea-fibre	Bœhmeria nivea.	Urticaceæ.	China, India, &c.	Various textile fabrics; the coarse kinds afford cordage, fishing-nets, sails, &c.
Rice-straw	Oryza sativa.	Gramineæ.	Europe, India, &c.	Fibre affords a soft porous paper.
Rice-paper	Aralia papyrifera.	Araliaceæ.	Formosa, China.	The pith of the tree is cut cylindrically, by sharp knives, into very thin sheets, affording "Rice-paper," used for artificial flowers, painting, &c., by the Chinese, and in this country. The stem resembles that of our elder-tree.
Ruffia	Raphia ruffia.	Palmaceæ.	Madagascar.	Thread is made from the leaves of this palm, and woven into Malagasy cloth, commonly used as garments by the natives.
Rushes	Juncus (various).	Juncaceæ.	Generally.	Brooms, mats, brushes, baskets, hassocks, &c.
Screw-pine Palm ...	Pandanus spiralis.	Palmaceæ.	Tropics generally.	The fibre resembles hemp, and may be similarly used.
Sedges	Cyperus (various).	Cyperaceæ.	Generally.	Brooms, mats, brushes, baskets, &c.
Silk-cotton	Bombax ceiba.	Bombaceæ.	South America.	(See Cotton.)
Straw	Various, as from Wheat, Rye, Barley, Rice, &c.	Gramineæ.	Generally.	Largely used for making paper, bonnet-plait, &c.
Sugar-cane	Saccharum officinarum, &c.	Gramineæ.	India, W. Indies, America, &c.	Fibre may be used to make paper, &c.
Sunn Hemp	Crotalaria juncea.	Or. Leguminosæ. § Papilionaceæ.	India.	Fibre an excellent substitute for flax.
Talipot Palm	Corypha umbraculifera.	Palmaceæ.	Ceylon.	Leaves used as umbrellas, tent-covers, &c.
Teazle	Dipsacus fullonum.	Dipsaceæ.	England, &c.	The flower of a plant largely used to raise the nap of woollen cloth.
Tucum Palm	Astrocaryum vulgare.	Palmaceæ.	Brazil, &c.	Leaves woven to make hammocks, &c.; they also afford thread.
Willow	Salix (various).	Salicaceæ.	Temperate Climes.	Baskets, bonnets, plait, &c.
Yercum-fibre	Calotropis gigantea.	Asclepiadaceæ.	India.	Resembles flax; the seeds are enclosed in a silky fibre, like thistle-down.

Having so far given a general view of the various kinds of fibres used in Textile Manufactures, we proceed to describe each in detail, commencing with :—

Cotton.

The Cotton Manufacture must be admitted to stand foremost of all British industries. For

Fig. 1.—Gossypium herbaceum—Cotton Plant.

Fig. 3.—Gossypium religiosum—Cotton Plant.

Fig. 2.—Short-Staple, or Green-Seed Cotton.

Fig. 4.—Flower-bud, flower, and the opened pod of the Cotton Plant.

nearly a century Manchester and Liverpool have been the great centres from which this branch of our productions in a manufactured state have spread. Manchester, in fact, may be considered at the present day as the centre which has given rise to some scores of places that have earned the district the name of Cottonopolis. Much of this expansion of the trade has been due to the introduction of the railway system. About half a century ago the cotton arriving from abroad, being landed at Liverpool, where there were then no cotton factories, had to be sent to Manchester by the slow process of canal or road conveyance. Within the memory of the writer, cotton goods manufactured in Manchester, if sent off by such conveyances on a Monday, would not have

Fig. 5.—Gossypium arboreum—A species of Cotton Plant.

arrived in London, at the earliest, until the following Friday. A journey by coach from Manchester to Liverpool then took about four hours. It will thus be seen how much we are indebted to Stephenson for the advance of this and every other manufacture of our own and other countries.

By far the largest portion of cotton used in this country is imported from the United States. There are chiefly four species of the plant from which our supply is drawn. The *Gossypium herbaceum* is that which affords the shortest staple, and is extensively cultivated in India, Egypt, China, and the eastern hemisphere, wherever cotton is produced. Until very recently, being coarse, short, of bad colour, and sent to market full of seed, &c., it was neglected by the manufacturers of this country; or, at all events, only employed to mix with the American sorts in spinning low numbers—its moderate price being the chief inducement. But owing to the American civil war, which commenced in 1860-'61, and the lengthened period during which it was carried on, East Indian cotton became in great request, and the exports to this country rapidly increased. There is no doubt that far more cotton has been at all times grown in India than in any other country; but the large annual consumption by the natives, and, until recent years, the want of proper land and water carriage, have always prevented any extensive supply being brought down to the seaports for shipment, unless the growers were stimulated by high prices, or by such occurrences as those we have just alluded to. The *Gossypium arboreum*, or cotton-tree (also a native of India and China), sometimes grows to a height of about twenty feet; whilst the species *G. herbaceum* (see Fig. 1) rarely exceeds twenty inches. The latter bears a pod of about the size of a walnut, in which the cotton is enclosed with the seeds.

The *G. Peruvianum* is a species of cotton primarily cultivated in the Brazils : it has a long staple; and some varieties are capable of producing an article almost equalling the famed Sea Island kind.

The species mostly cultivated in the United States of America, is the *G. Barbadense:* and it is this and its varieties from which the most valued kinds of cotton—the American and Sea Island—are produced. The cut (Fig. 28, at page xl. in the Introduction) gives an idea of the appearance of the leaves, flowers, pod, seed, &c. The cotton produced from this species is silky, usually of a rich white colour; and that grown in Alabama, and the Southern States, generally has been, till late years, the chief staple of the cotton manufactures of this country. In fact, to suit the length and quality of the staple of this cotton, most of the machinery in Lancashire and the other cotton-spinning districts has been erected : some idea may hence be gained of the confusion and distress which the American Civil War created; for not only was the question of quantity of importance, but the article which had been imported from India as a substitute, being of a short and coarse staple, was, to a large extent, utterly unsuited for the machinery then in universal employment. The Sea Island cotton, so valued for its long staple, is grown near the sea-coasts of Florida and Georgia, where it has the advantage of the saline matter blown to the land on which it is growing. This seems essential to the production of this valuable, long-stapled cotton, for if raised in more inland districts, the staple becomes shorter, and the cotton shows a decided deterioration in many respects. Generally speaking, indeed, cotton should be grown in situations where access of sea-air, or a good supply of saline substances, is possible. This species is illustrated by Fig. 29, page xli. in the Introduction.

The species which we have mentioned are those

chiefly cultivated in the districts named; but cotton, of the same species, is now largely produced in many other places. Some excellent specimens were shown in the International Exhibition of 1862, from Algiers, many parts of the western coasts of Africa, from Natal, &c. Jamaica, and many other of the West Indian islands, produce considerable quantities; and, at every place where the growth of the plant is possible, former occurrences in America have stimulated the planters to exert their best efforts in raising this valuable commodity. There are numerous varieties, or perhaps species. Fig. 2 represents a short staple or Green Seed Cotton, and Fig. 3 another species, the *Gossypium religiosum*. The *Gossypium Indicum*, or Indian cotton, is a tree-like variety, having a woody stem rising to the height of ten or twelve feet. It continues in full bearing during several years. The *Gossypium hirsutum, vitifolium, religiosum, tricuspidatum*, &c., are other varieties, differing in various points from those above named.

The colour of the seed seems to be connected in some way with the quality of the cotton fibre. The number of seeds in one pod varies greatly, the range being from ten to thirty. There is a West Indian wild cotton-plant, of which the seeds are rough and black, and the cotton pale red, with so short a fibre that it cannot be spun. The Indian cotton has a dark-brown seed streaked with black, and fibres very white and fine. There is a kind which produces fibres almost equal to silk in beauty and fineness, and at the same time very elastic and very white; but it is not much cultivated on account of a difficulty in cleaning it, arising from the close adhesion of a kind of green moss to the mass of fibres. The seeds of Jamaica cotton are smooth, but so brittle as to break in clearing the fibres from them, so that the species is much less valuable than it would otherwise be. The "Sea Island cotton," derived from the "*herbaceum*," and brought from Georgia in the United States, is, as already stated, commercially the most valuable of all, and that to which the Liverpool merchants direct more of their attention than to any other.

The general method of planting the crop may be described as follows:—The seed is sown on ridges, surrounded with furrows, for the purpose of draining off superfluous water. Sowing-time extends from the beginning of March to the end of April; the early part of the latter month being considered the most eligible, because of their being less danger to the young plants from the occurrence of frost—that fearful bane of the cotton-planter. After the plants have attained a moderate height, they are thinned out, so as to remove those that promise badly, and to leave sufficient space between those that are vigorous; this space varies from about ten to twenty inches. The soil is carefully weeded, and the plants are still further thinned, if their luxuriant growth should require that process as the season advances.

As the summer approaches, and when the frost has disappeared, the crop is liable to injury from heavy rains, and the attacks of a caterpillar which feeds voraciously on the leaves of the plant. The blossom then appears, varying in colour from yellow to red, and, lastly, dark brown. The pod succeeds, and, about August, the picking season commences, which lasts for some months. The appearance of a pod bursting is very beautiful as it rests on the plant, being varied by the contrast of the colour of the cotton with the green leaves of the shrub, and the beautiful flower, either fully opened or opening on the stems. The cut (Fig. 4), gives an illustration of this appearance. After the cotton is picked, it is thrown into bags hung round the necks of the negroes, who convey it to the drying-room, where it is exposed to the air to remove all moisture, which would otherwise injure the fibre. The next step is to free it from the seeds and the husk of the pod; and on the care devoted to this depends, to a large extent, the commercial value of the cotton, a clean article always obtaining the highest price in the market.

We may here call attention to the microscopic appearance of the cotton fibre.

These fibres, which seem to bear nearly the same relation to vegetation that hair does to animals, partake of the character of cellular tissue, in being thin and transparent. They are long, weak tubes, which, when immersed in water and examined under the microscope by transmitted light, look like flat, narrow, transparent ribands, all entirely distinct from each other, and with an even surface and uniform breadth (see Fig. 7). It is only in some few cases that *joints* are observable in the fibre; and when this happens, the joint is marked by a line directly across the breadth. Sometimes there is an indication of fine grains in the interior of the tube; but in general the tube appears to be empty: if strained singly, they have little strength; so that it is only by combining many of them together that they acquire sufficient tenacity for textile purposes. Fibres of flax or linen present a very different appearance from these; for though they are tubular, yet these tubes are so grouped up into bundles that it is difficult to detect them singly even by the microscope. The tubes are thick-sided, and are formed of woody tissue, those of cotton being cellular tissue. The joints of the flax-fibre are oblique and overlapping; and throughout its whole structure there is greater strength in the individual fibres than in those of cotton; a circumstance which sufficiently explains the superior strength of linen over calico or any other kind of cotton goods.

Dr. Ure gives the result of an extensive series of examinations to which he subjected cotton-wool as well as other fibres employed in textile manufactures; and the result is well calculated to excite surprise on account of the extreme minuteness of the fibres so examined. For instance, Sea Island cotton has an average diameter of about $\frac{1}{2000}$ of an inch; Upland cotton, $\frac{1}{6000}$; Surat, $\frac{1}{500}$ to $\frac{1}{2000}$; and various other kinds have a diameter varying from the one to the other of these two extremes. The fibres generally terminate in very fine points, and have also fine

edges. The entanglement of the filaments, to which the superior spinning qualities of cotton are due, is ascribed chiefly to their spiral structure and their elasticity, inasmuch that when one is pulled out, it draws others along with it. "If, during this extrication of the filaments," says Dr. Ure, "a twisting motion be communicated to them, they will form a cohesive thread. The finer, the more uniform, the more cylindrico-spiral, the longer, and more elastic the filaments are, the more capable they will be of forming fine yarn. When they are short, and consist of rather broad and flimsy ribands, they will be ill adapted to machine-spinning, though still susceptible of being spun by the tact of delicate fingers. We can thus understand how the Hindoo women manage to spin fine yarn from the Dacca cotton, which is the growth of an unequable wool consisting of flimsy ribands, like most of the Indian cottons. . . . . There can be no doubt that the cotton filaments are hollow cylinders, prior to the state of maturation: they then become flattened and tortuous, in a greater or less degree. The more nearly cylindrical they remain, the stronger and more pliant to the spindle will they be found."

Figs. 8 and 9 give a highly magnified view of cotton fibres, from which some of their special characteristics may be judged. The cross-lines in Fig. 9 show how the diameter of the fibre is measured in the microscope, fine lines of spiders' web being placed at right angles to each other for the purpose.

To an ordinary observer the fibres of cotton, as seen by the naked eye, present comparatively little difference except as regards the colour of them *en masse.* But the cotton broker and cotton spinner, only to a very moderate extent depend on colour, although in some cases it is an important element. We have already noticed some of the peculiarities of cotton, besides that of colour. The fineness, length of staple, softness, equality, freedom from knots, dirt, sand, and other impurities, are of great importance. If a sample of cotton be taken and drawn out by means of the thumb and two fore-fingers of the hands, until the fibres are placed parallel to each, as they have afterwards to be placed during the process of "carding," the following characteristics may be noticed. Selecting out of Indian cotton, the specimen will, if of Surat, show a darkish colour; short staple, harshness to the feel, and if too much stretched it will break. The so-called Madras cotton has a lighter colour, but is still harsh to the touch, and of short staple. If these cottons are spun individually or mixed, they produce a yarn that is porous, rough, and specially suitable for candle-wick and coarse cloths. Hence the coarse calico made in India has a bulky appearance, and roughness of surface.

The so-called Smyrna cotton, although of far superior character, as regards colour, has similar qualities; and many years ago we remember that it was eagerly sought for to make the wicks of the best mould candles.

On the other hand, almost every variety of cotton produced in the United States has a white colour, is soft and silky to the touch, makes a close yarn, and a smooth calico; bleaches well; and, for this and many other reasons, commands the greatest demand in the market.

Sea Island has a long staple, but not so large as the Egyptian variety. Hence these are used for spinning what are called "fine numbers." Many years ago we saw a curiosity in this respect, being that of a pound of the best staple cotton of this class spun into what is called 480s, which means that 480 hanks, measuring about half mile each in length, weighed one pound avoirdupois.

An experienced person gradually acquires by habit a remarkable facility in the examination of cotton fibre; so much so, indeed, that even in the dark he can determine the country, quality, and value of the cotton under examination. The writer has frequently selected in the middle of the night, bales of cotton required for immediate use, that had been previously cut open and exposed to the air, by simply passing the palm of the right hand over the surface of the wool.

As it is an important matter to send the cotton to market in as clean a state as possible, both for saving of freight and increase of price, many contrivances have been introduced for this purpose. In India, however, the greater part of the cotton is picked by hand. Abel describes a machine which he observed the Chinese to use for this purpose :—"It consisted of two wooden cylinders placed horizontally one above the other, on a stand a few feet from the ground. The cylinders, very nearly touching, were put in motion by a wheel acted upon by the foot. The cotton being brought to one side of the crevice intervening between them during their revolution, was turned over to the opposite; whilst the seeds, being too large to enter, fell at the feet of the workman." Thumberg, in Batavia, saw cotton cleansed from the seed by being laid out on extended cloths, and beaten with sticks till all the seed was perfectly separated from it.

The machine called a *gin* is very much used in cleaning cotton in America. In its simplest form it consists of two or three fluted rollers set in motion by the foot in the manner of a turning-lathe, and by its means one person may separate and cleanse sixty-five pounds per day; whereas in mere picking by hand, as is generally done by the Hindoos, only one pound a day can be cleansed. The larger machines used in the United States are much more powerful, and act in the following manner :—They consist of two wooden rollers about an inch in diameter, placed horizontally and in contact. Over them is fixed a sort of comb, having iron teeth two inches long, and nearly an inch apart; this comb is of the same length as the rollers, and so placed that its teeth come nearly in contact with them. When the machine is set in motion the rollers are made to revolve with great rapidity in opposite directions; so that cotton, being laid upon them, is by their motion drawn in between the two, whilst no space is left for the seed to pass with it. To detach these from the fibres of cotton in which they are enveloped, the

same machinery which impels the rollers gives to the toothed instrument above a gentle oscillating movement, by means of which the pods of cotton as they are cast upon the rollers are torn open, just as they are beginning to be drawn in; the seeds, now released from the coating which had encircled them, fly off like sparks to the right and left, while the cotton itself passes between the cylinders. The sharp iron teeth of the comb moving with great velocity sometimes break the seeds, and the fragments are drawn in between the rollers with the cotton: these stray particles are afterwards separated by hand, a process which is called *moting*.

Fig. 6.—Gossypium tricuspidatum—A species of Cotton Plant.

Some of the coarser kinds of cotton in Georgia were originally cleansed by *bowing*, or agitation with a bowstring; and in the market the term of "bowed" cotton is still used, although the cotton is now cleansed by other means. The bowing process is still carried on in many parts of the East, in the manner shown in Fig. 10. Abel, speaking of the Chinese bowing instrument, says:—"It is a very elastic bow with a tight string. In using it the carder places it in a heap of the material, and having pulled down the string with some force, he suddenly allows the bow to recoil; the vibration of the string scatters the cotton about, and separates it into fibres freed from knots and impurities."

The *saw-gin* (Fig. 11) is another contrivance for separating the seeds from the fibres, adapted for a particular kind of cotton which could not be cleaned conveniently in any other way. The American inventor, Mr. Whitney, had to suffer much of that unfair treatment which so often falls to the lot of inventors. Dr. Ure says that Whitney, "having spent a winter in completing his machine, showed a few friends that it could separate more cotton from the seed in one day by the labour of one man than could be done by the existing methods in a month. The construction of this instrument was an event of such consequence as to excite a universal interest in the State of Georgia, where Mr. Whitney then lived in narrow circumstances, under the roof of an hospitable friend. Neither the sentiments of justice nor the fear of the law could restrain the eager crowd from breaking into his workshop by night and carrying off his wonder-working tool. In this dishonourable way the public acquired possession of Mr. Whitney's invention before the model was finished to his mind, and before he could secure the protection of a patent. Many copies were immediately made from it with slight variations, in order to evade the patent which he obtained for it soon afterwards. Thus the inventor of a most ingenious machine was not suffered to reap in peace a reasonable share of the fruits of his labours, which proved so beneficial to his country." The machine here alluded to is provided with a number of circular saws, so placed that when the cotton passes down through an opening into which it is placed, it is caught by the teeth of the revolving saws, and disentangled.

Numerous inventions have been brought out, and improved methods adopted on those already described. Some of them may be eventually noticed when we detail recent improvements in the manufacture of cotton.

Fig. 7.—Cotton Fibre, magnified.

Whatever may be the mode adopted, when the cotton is cleaned, it is packed into bags for

shipment. The Sea Island cotton is packed in hempen bags made of Scotch sack-cloth, forty-two inches wide in the web, weighing about a pound and a-half to the yard. Each bag is capable of holding on an average about three hundred pounds of cotton. The room into which the cleaned cotton has passed is set apart for the packing operation, and is kept free from dust. Adjoining to it is a small room under the same roof, with a round hole in the floor just large enough to contain the bag when full of cotton. The open end of the bag is fastened by twine to a wooden hoop which extends beyond the hole, so as to hang the bag upright by its mouth. A man then gets into the bag with a heavy wooden or iron pestle in his hands. Cotton is put in, which he first presses down with his feet, and then beats with the pestle, so as to make it occupy as little space as possible. In this way two men proceed, assisting each other, until the bag is filled.

Instead of this method, which much resembles that of packing or bagging hops in this country, cotton is sometimes compressed into bales in a more dense manner. As the charges of sea-transport are made by bulk rather than weight, it is of the utmost importanco to diminish the cost of freight by packing the cotton into as close a space as possible. This is effected by means of a Bramah or other hydraulic press, in which the cotton is so compressed, that about $3\frac{1}{4}$ cwt. is forced into a bale measuring about five feet long, and twenty inches to two feet square—the usual size of bales imported into this country. Some kinds are still sent in bags loosely; but the quantity thus reaching this country is very trifling. The compression of the cotton is also favourable to its safe transport, for it is less liable to be discoloured; and if, by accident, it should become wetted, the water soaks in to a very small extent only. Indeed, we have seen bales recovered from a shipwreck having the centre quite dry, although they had long been floating in the water.

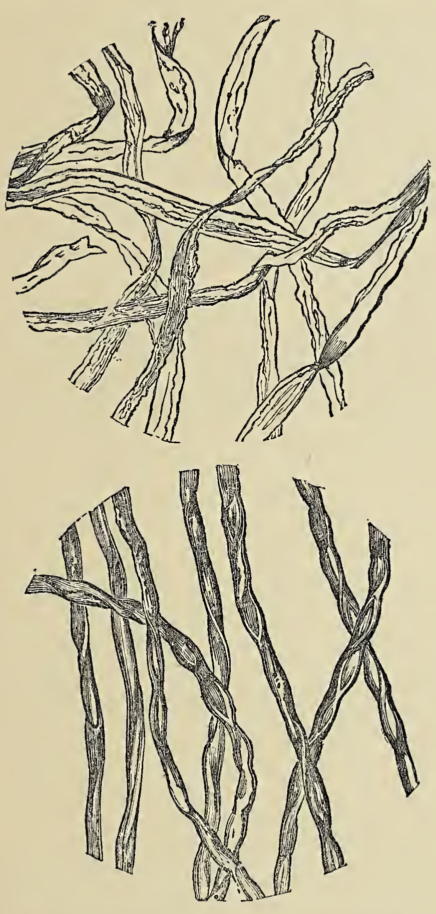

Fig. 8.—Cotton Fibres, greatly magnified.

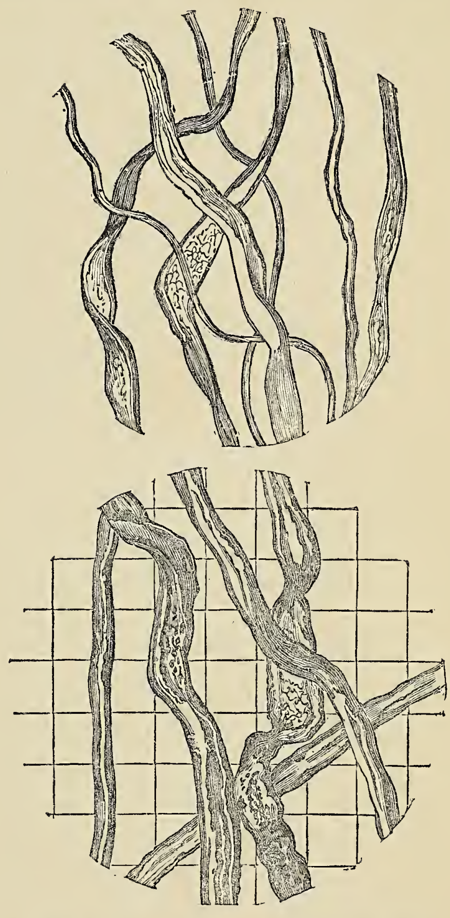

Fig. 9.—Cotton Fibres, greatly magnified.

Having thus described the growth, gathering, cleaning, packing, and export of cotton from foreign countries to our islands, we next have to deal with the various mechanical means that are

employed to convert it into the various forms of yarn, cloth, &c. But before doing this we may show how the Hindoos have long managed to produce fine yarns and cloths without what, for all practical purposes, we may call machinery.

That the cotton goods made in India long preceded those of England in point of time, we have abundant evidence. Defoe, about a hundred and sixty years ago, made the following condemnatory remarks on the use of cotton goods, deeming it an injury to our home manufactures that such should be the case :—"We saw our persons of quality dressed in Indian carpets, which, but a few years before, their chamber-maids would have thought too ordinary for them; the chintzes were advanced from lying on their floors to their backs, from the foot-cloth to the petticoat; and even the Queen herself at that time was pleased to appear in China and Japan, I mean with China silks and calico. Nor was this all, but it crept into our houses, our closets and bedchambers; curtains, cushions, chairs, at last beds themselves were nothing but calicoes or Indian stuffs; and, in short, almost everything that used to be made of wool or silk, relating either to the dress of the women or the furniture of our houses, was supplied by the Indian trade."

In India, women of all castes prepare the cotton-thread for the weaver, spinning the thread on a piece of wire, or a very thin rod of polished iron with a ball of clay at one end; this they rotate with the left hand, and supply the cotton with the right; and the thread in this state is wound upon a stick or pole. This is the primitive "distaff" spinning, of which a sketch, taken from Montfaucon, is given in Fig. 12. But for coarser kinds of yarn, the Hindoo females employ a simple form of spinning-wheel (Fig. 13), in front of which they sit on the ground. The cotton is cleaned for them by men who use the bowstring, as before mentioned. The bow is made of bamboo, and is fastened by strings to the wall of the room, at a height of about five feet from the floor. To the middle of this bow a card is tied, to which a second bow is attached of a larger size, strung with thick catgut; this second bow hangs about two feet above the ground. The man sits down, lays hold of it with the left hand, and strikes the string of the bow with a strong ebony stick held in his right hand; the vibration of the string causes the cotton to fly about and become loose and disentangled.

From a manuscript account of the Hindoo cotton manufacture, written by Dr. Buchanan, and quoted by Dr. Ure, several interesting details may be gleaned. A good deal of the cotton is freed from the seed by the women who spin it, and a part of this is also beaten or "battened" by the same persons; but there is a class of men called Dhuniyas, who make a profession of cleaning and beating cotton. Perhaps one-third of these have stock enough to enable them to buy a little cotton, which they clean and then retail; but the greater number work entirely for hire. In many places these men are paid for their services in grain instead of money. "In every division," says Dr. Buchanan, "I procured an estimate of the proportion of women who spin cotton, of the average quantity of cotton that each spins, and of the value of the thread. Such estimates are liable to numerous objections; but it is probable when a number of them are taken, that the errors of the one will be nearly corrected by those of the others, so that the average will not be far from the truth. Allowing that the women of an age fit to spin are one-fifth of the population, the estimates that I procured will give for the whole thus employed 330,426 spinners (this relates to the provinces of Bahar and Patna). Now by far the greater part of these spin only a few hours in the afternoon; and, upon the average estimate, the whole value of the thread that each spins in the year is nearly 7R. 2A. 8P." If this alludes to the rupee equal to rather more than two shillings, the amount is sufficiently small, but it is well known that the money-value of labour in India is so small as to be hardly conceivable by work-people in this country. Indeed, it is stated that the spinners of the very finest yarns earn only about three farthings per day for their labour.

The delicacy of the Hindoo organization enables the spinners and weavers to produce goods of exquisite fineness. Orme mentions an example in relation to the silk-twisters of Bengal, which is of the same character as that often observable in cotton spinning. These women wind off the raw silk from the pod or cocoon; a single pod is divided into twenty different degrees of fineness; and so exquisite is the feeling of touch, that while the thread is running through their fingers, too swiftly for the eye to follow it, they will break it off exactly as the quality changes, and determine on the instant which among twenty different qualities is that at which they have arrived. The fineness of the muslin made by them from cotton has been the theme of many stories. Tavernier relates that a Persian ambassador, on his return from India, presented his king with a cocoa-nut, which contained a muslin turban thirty yards long, and so fine as hardly to be felt when expanded in the air. A broad web of some of their muslins may be drawn through a finger-ring.

The cotton, when spun by the Hindoo women, is delivered to the winders, who are chiefly young wives and girls, and who wind it into a skein or hank. Next comes the process of warping, by which the threads are ranged parallel for the weaver; and afterwards comes the weaving, of which in connection, or rather contrast with English weaving, we shall have to speak further on. All these persons, in an earlier period of the late East India Company's history, were employed by the Company in a curious way. The Company advanced, through their Residents at the different states, not only the cotton, but the funds required for the support of the workman and his family. The Resident had under him a number of subordinate officers; who, in their turn, had control over a corps of native clerks and inspectors. The

Resident sent out to the native merchants proposals as to the kind and quantity of the goods required, and the merchants negotiated with the workpeople as to the terms on which their fabrics should be supplied. The Resident gave the money and materials to the merchants, who were accountable for the due return of the produce, and the merchant distributed them to the workpeople. The Resident never interfered in the arrangements, unless any disputes arose between the contractors and the workpeople; in which case he sent his native overseers to settle any differences. When the weavers were not occupied by the government, the Resident used often to engage their services on his own account; and this system sometimes gave rise to abuses which required correction from head-quarters.

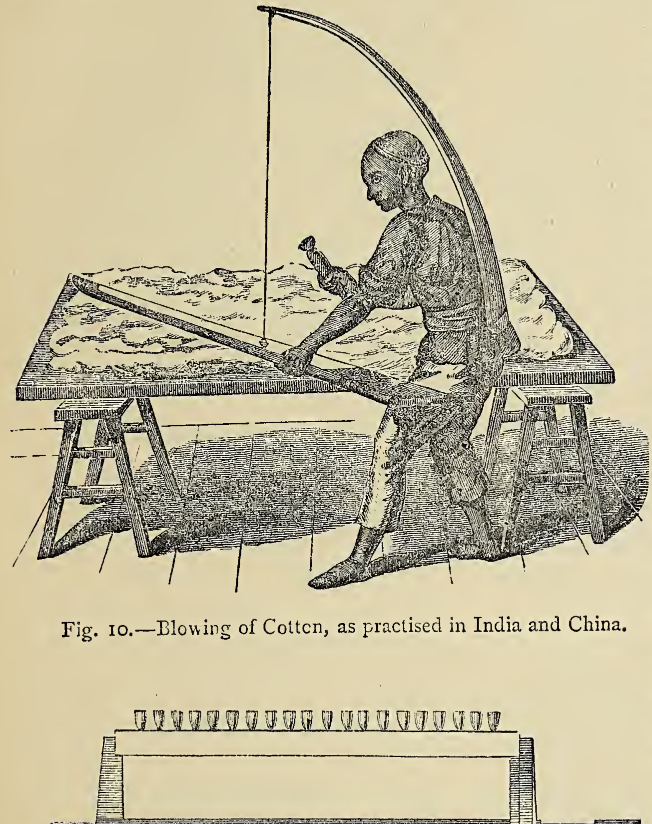

Fig. 10.—Blowing of Cotton, as practised in India and China.

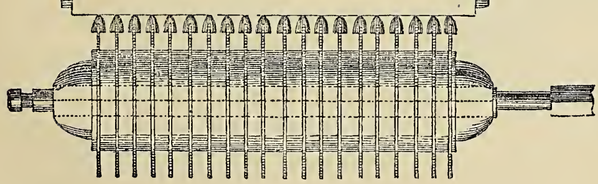

Fig. 11.—Whitney's Saw-gin.

Respecting the peculiar *natural* fitness of the Hindoos for this kind of work (when not competed against by machinery) Dr. Ure remarks:—"In Coromandel, and in the province of Bengal, it is rare to find a village the least retired from the public road, where every man, woman, and child is not employed in making a piece of cotton-cloth. There are many districts in Asia and its islands equally propitious to the growth of cotton as Bengal, where the sun is as sultry and the people as unwarlike; yet this elegant branch of industry has hardly an existence among them. A more just cause for its exceeding prevalence in Southern Hindostan is the peculiar delicacy of tact of the natives of that region, for as much as they are deficient in mere muscular strength, so much are they endowed with exquisite sensibility and pliancy in every organ and limb. The hand of an Indian cook-maid is more delicately formed than that of a European beauty. An English workman could scarcely manage to work a piece of canvas with the simple loom with which the Gentoo weaves his gossamer muslin. His calling receives encouragement from public estimation. A weaver is there no ignoble caste, upon which patrician Hindoos can look down with disdain. He takes rank next to the scribe, and above all other mechanics. Were he to condescend to the performance of any drudgery out of the line of his business, he would lose his caste. This distribution of labour is of very ancient date. Every peculiar kind of cloth is the production of a peculiar district, in which it has been fabricated from generation to generation by certain races of men, each continuing to practise with minute precision the process of his predecessor. Thus it was their fine physical organization, guided by hereditary industry and experience, which gave to Hindostan the monopoly of the cotton trade for at least three thousand years.

We thus see that despite the enormous advances which modern machinery gives, we have been forestalled by ordinary hand labour for many centuries.

On arriving in this country the cotton in the bales, being long stowed in the hold of the ship, reaches the consumer in an almost solid state. We have seen bales of cotton, after the outside ropes and sacking had been removed, attain

twice or thrice their original dimensions by exposure to the air for a few days. After opening, the cotton is classified according to its qualities, to suit the different kinds of yarn to be prepared from it. Although the fibres form very light locks or tufts when they have been cleaned from the seeds in America or India, yet they are so powerfully compressed in the process of packing, that the tufts become matted and

Fig. 12.—Distaff-spinning. (From Montfaucon.)

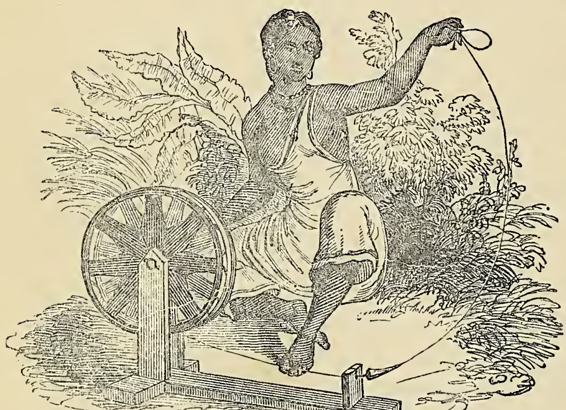

Fig. 13.—A Hindoo Woman spinning Cotton.

entangled, and require opening before anything else can be done ; because, in all the subsequent operations, each fibre must be combined unbroken with others, to form the collected group or thread. This disentangling is effected in various ways, according to the quality of the cotton, or the general arrangements of the factory. The finest is often opened and picked out by hand. It is placed on a table covered with a kind of net or mesh-work, and, after being lightly beaten with slender rods, the knots and other impurities are removed by the fingers. Another mode of disentangling the fibres is by "scutching" them: that is, spreading them out on a springing or elastic table, and beating them by a series of parallel rods until the fibres are disengaged. We have found in practice that cotton picked by hand and thrown in opened tufts on a stone floor becomes wonderfully improved in a few days, and loses far less in the subsequent operations of willowing, &c., than cotton that had not previously been so treated.

But the most usual mode of effecting this opening disentanglement is by the use of some kind of rotating instrument called a *willow*, of which different forms have been invented. In Fig. 14, there is a cylinder (seen separately in the lower part of the cut) having several teeth or spikes on its surface, and capable of revolving within a kind of case or box very near another series of spikes. A door is opened, and a boy or man puts in an armful of cotton, and closes the door again. The cotton is then thoroughly disentangled by being caught between the teeth during the rotation of the cylinder, and the dust and impurities fall through a kind of sieve to the bottom of the machine. After it has been worked about for a few seconds, the boy opens the door, removes the cotton which has been disentangled and cleansed, and puts in a new supply. Another willow, used in Normandy, consists of an open cylinder, placed in an inclined position with an opening at which cotton can be introduced in it. The cylinder is made to rotate, and while the cotton descends gradually to the lower end, it is caught and tossed by spikes within the cylinder. A more complete machine, however, is such a one as that sketched in Fig. 15. There is a cone revolving within a cylindrical case; on the surface of this cone are a number of points or spikes; and the cotton, when disentangled by this means, is let out of the machine, and deposited in an equable layer.

When the fibres become completely opened, and all the dust and dirt is carried off by a powerful current of wind, excited for that purpose, matters are then ready for that highly curious series of processes in which the cotton is combed, carded, or straightened out in the manner requisite to form thread or yarn. This is in the first instance brought about by some such comblike instrument as those shown in Figs. 16, 17, 18; or rather, as the teeth are here only seen sideways, we should say that each instrument is a kind of *brush*, having a large number of wire teeth fixed in a board or handle. In one of the figures (Fig. 16) it is seen that each tooth consists of a piece of wire bent into the form of a staple, and then having an angle

or elbow made in each leg of the staple. These teeth are fixed into a very smooth and straight piece of leather or other stiff material, by holes pierced for that purpose; and very great care is taken that the angle at which the teeth lie should be the same throughout. When the proper number of these wires is fixed to the leather, the whole is called collectively a *card*. The making of these cards is now conducted by one of the most elaborate machines ever used in art. It straightens the wire from a coil, cuts off a piece of sufficient length, bends it into a staple-form, gives the angle or elbow to each wire, pierces the holes in the leather or other material, and inserts the wires—the machine perfecting in this manner four or five hundred teeth in a minute!

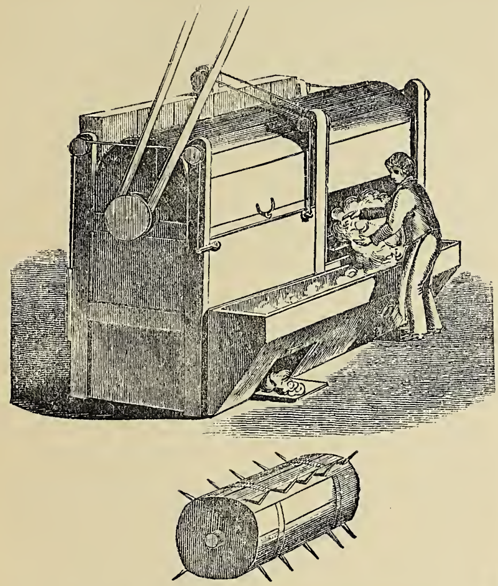

Fig. 14.—Willowing-machine for Cotton.

In employing the cards two sets of teeth are made to act on opposite sides of the fibres of

Fig. 16.—Teeth for Carding Cotton.

cotton. If two cards be placed as in Fig. 17, the one over the other, and the teeth inclining in the same direction; and if further a tuft or lock of cotton be placed between them, and the cards be moved in the direction of the arrows, then the cotton will be subjected to a twofold action. The upper teeth will endeavour to draw them in one direction, while the lower will pull them in another: the tuft will thereby be separated and drawn asunder in such a manner as to lay the fibres in some degree parallel, instead of

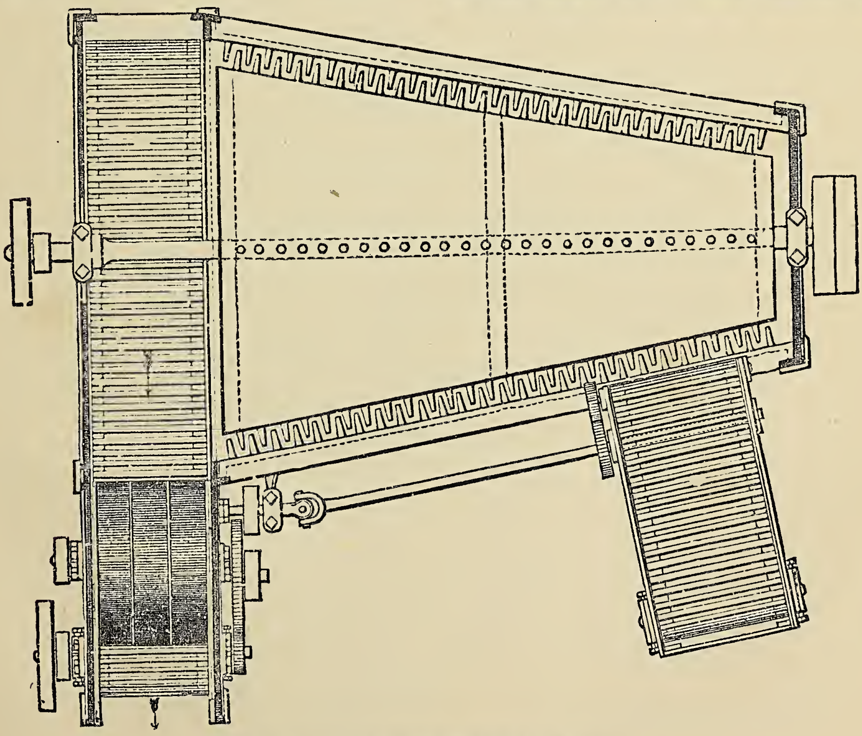

Fig. 15.—Willowing-machine for Cotton.

being all confusedly heaped up together. If the cards be arranged, as in Fig. 18, with their teeth inclining in opposite directions, then the tendency is for each card to "doff" or sweep off the cotton fibres from the other; and it is on some such a principle as this that the cotton is removed from the carding-machines. Originally the cards were made flat in form, and were worked against each other by hand or by machinery; but in the more improved mode of proceeding there are several cylinders placed near together (Fig. 19), each covered externally with cards, and by the rotation and mutual action of these cylinders the cotton becomes combed out so as to assume a tolerably even and parallel arrangement.

There is, however, a distinction to be observed in the terms used to designate the different forms and uses of the cards. Those which are nailed lengthways, on the large cylinder at the centre of the engine, are properly "cards;" whereas, the smaller rollers (which revolve over this cylinder), and the cylinder, which receives the cotton proceeding towards, and next to the card, are covered with "fillet;" that is, a long ribbon of "card," wound round and round the small rollers spirally, until they are completely covered with it.

We may now proceed to trace the progress of the cotton through the carding-engine. In the cut (Fig. 19) we notice, on the right-hand side, the web of cotton brought from the last preparatory process. The cotton is caught by the teeth of the large centre cylinder, which receives and distributes the steam-power by means of a strap from a shafting over-head. On the shaft, and on the axle of the carder, pulleys are fixed, round which the strap passes.

As soon as the cotton reaches the wires on the large cylinder, it is also brought into contact with the wires of the small rollers observed on the top of the large cylinder, and which are caused to rotate by means of a proper arrangement of tooth-wheels, noticed, in part, at the side of the engine. The fibres are thus gradually laid parallel, and arrive at a medium-sized cylinder (shown towards the left of the cut), in front of which is a kind of saw, or comb, that rises and falls, detaching the cotton from the cylinder in the form of a gauze-like web. Thence the web passes through a kind of cone, and is received in cans, becoming what is called a "sliver." To explain more fully the mutual action of the rollers and cylinder, we must revert to Figs. 17 and 18. In the former we notice that the teeth move in opposite directions; and thus cotton on the upper series would be pulled in the opposite direction, as shown by the arrows. But in Fig. 18, the "cards," or rollers, are supposed to move in similar directions: hence, by the lower, the cotton would be stripped off from the upper, whilst still moving in the same direction. Now, it is by a proper arrangement of these two motions that the carding process is completely effected.

The sliver, or long ribbon of cotton produced from the carders, has now to undergo the process of "drawing;" that is, it must be made of an even thickness throughout, and its width diminished. This is effected by the drawing-frame represented in the following cut (Fig. 20). On the left we notice the cans containing the first slivers: in the centre are rollers, between which the slivers pass; and on the right is a can, which receives the newly-formed sliver. The rollers are of two kinds, the upper being covered with leather;* and the lower are of iron, which is fluted on the surface. Each series, commencing from the left, revolves faster than the preceding one, so that No. 2 extends the sliver as it passes from No. 1; and similarly, No. 3 extends it still more. Four set of slivers supply each set of rollers; and after drawing they are united to form one, by which an even and regular sliver is obtained.

The sliver, thus produced, is next converted into a "roving." This is effected by giving a moderate amount of twist to the cotton, so as to form a yarn of about the thickness of a cedar pencil. The process so nearly resembles spinning, if not practically, at least in principle, that the description of the latter, which we shall presently give, will be sufficient to enable the reader to understand how a roving is produced.

The next process in the preparation of cotton for textile manufactures, is that of spinning. The art of spinning by hand is of the greatest antiquity, and was, at all times, considered an honourable occupation of women in any rank of life. Scriptural, Grecian, Indian, and Chinese history constantly refer to it; and, at the present time, in India and China, millions gain a subsistence by hand-spinning. It is a remarkable fact that the Indian women can spin, from the coarse and short staple of their cotton, a far finer thread than our most perfect machinery can produce, owing perhaps to the extreme delicacy of their physical organisation (see *ante*, p. 15). The Dacca and other muslins, so highly valued for their beautiful fineness, completely surpass the best productions of our looms; yet, for coarse articles, such as calicoes, both China and India are indebted for their supply to us. In such articles the economising power of machinery is strikingly evidenced; for, although the wages in India and China do not exceed one penny per diem, we can buy the raw cotton in those countries; bring it home to Manchester; spin, weave, and bleach it; and returning it to Bombay, Calcutta, &c., can undersell the natives in their own markets.

The "rovings," the production of which we have described, form the material from which the yarn is spun; and this operation involves two processes, which are conducted by the same machine: they are—drawing and twisting.

The spinning-frames employed for this purpose are of two kinds, and are respectively termed the *throstle*, or *water-twist*; and the *mule*

* The writer patented, in 1850, the use of India-rubber for coating the rollers, in place of leather; a method which has been much adopted and approved of, for the spinning of cotton, wool, &c. It prevents "lapping," or the rolling of the fibre round the rollers—especially in damp weather; a result which materially lessens the production of yarn, and tends to injure the machinery.

—the terms water and mule being primarily derived from the source of power by which the engines were driven, before the extended application of steam was effected in our manufacturing districts. There is also a manifest distinction in the characters of the yarn produced by these; the water-twist being hard, strong, and wiry; whilst mule-twist is soft and woolly. They are, accordingly, employed for very different purposes in weaving and other subsequent operations.

Commencing with throstle-spinning, we may

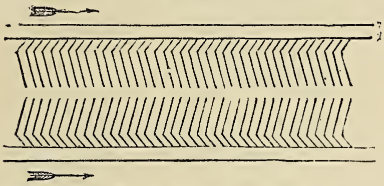

Fig. 17.—Teeth for Carding Cotton.

observe that the drawing, twisting, and winding processes proceed simultaneously; whilst in mule-spinning, the two first are followed by the other; yet all of them, in this case, are done on the same machine.

The cut (Fig. 21) represents a portion of a throstle-frame. On the left, at the top, the

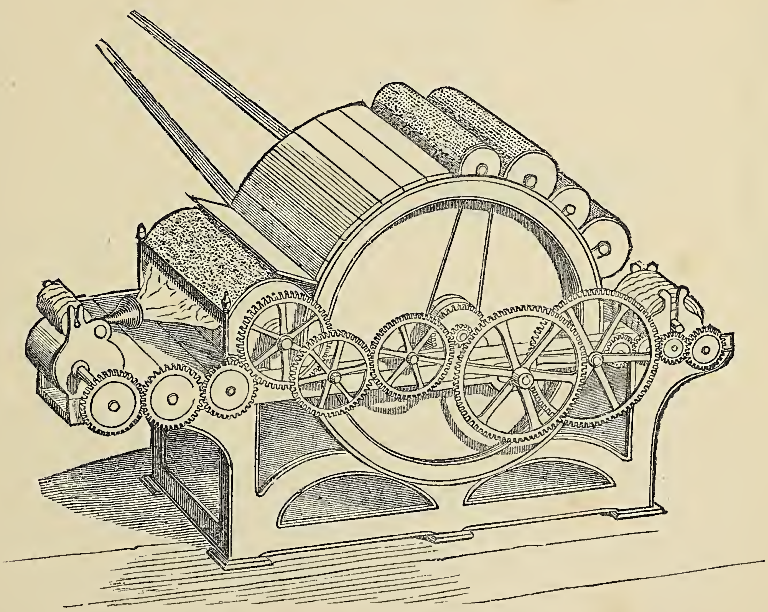

Fig. 19.—Carding-engine for Cotton.

rovings, *a*, enter a pair of rollers, *b*, and, passing to a second pair, *c*, they are drawn to a thinner size; this drawing is still further effected by the next pair of rollers, *d*, from which the attenuated roving, *e*, proceeds to a spindle and fly, *f*. Inside of the arms, *g*, of this fly, a bobbin, *h*, is placed, resting loosely on the spindle carrying the fly, and revolving independently of it. The fly revolves rapidly, and twists the roving, which is at the same time, as yarn, wound on to the bobbin, *h*. By means of double cones, &c., the relative speed of the fly and the bobbin is regulated, which, of course, is necessary, because, as the bobbin becomes covered with the yarn, it gets thicker and thicker, and so would wind on the thread too rapidly. Again, the thickness or fineness of the yarn is regulated by this, and also by the amount of drawing effected by the rollers.

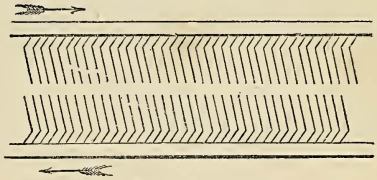

Fig. 18.—Teeth for Carding Cotton.

Mule-spinning is conducted on an entirely different plan. The rovings, on their bobbins, are arranged on an upright stand at the back of the machine, as marked *a*, *a*, *a*, in the cut on page 21, which represents a self-acting mule-spinning frame. Thence the roving-threads, *b*, *b*, *b*, proceed to three rollers, *c*, whose office is precisely similar to those described in connection with the throstle-frame; but here the identity ceases. From these rollers, the roving, *d*, passes to a spindle, *e*, whose office is to draw and spin the yarn, and afterwards to receive it. The spindle, *f*, which is a continuation of *e*, revolves in a carriage, *g*, which, by means of a chain, &c., can travel to-and-fro for

a distance of about five feet from the frame, *h*, by aid of the wheels, *l*, *l*, travelling on the tramway, *k*. When the carriage, *g*, runs *from* the frame, *h*, the roving is stretched or drawn from between the rollers, *c* (Fig. 22), and the spindle, *e*, and it is also twisted. When *g re-approaches* the frame, *h*, the roving, *d*, is wound on to the spindle, *e*. A "cop"—that is, a conical cylinder of yarn—is thus gradually formed on the spindle. Girls are employed as "piecers," whose business it is to mend those threads which are broken during the stretching or drawing process; and beneath the frames are boys, who, during the drawing out of the carriage, sweep up the waste flue which falls beneath.

When the spindles are thus filled with cops, which are generally about five inches long, and an inch thick, they are removed; the threads reaching from the rovings are fastened to the eye of the spindles, and the process of refilling the latter is again commenced.

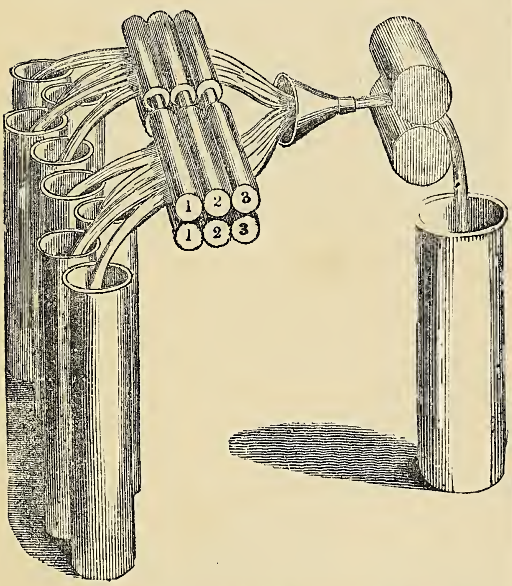

Fig. 20.—Apparatus for "Drawing" Cotton.

Whether water-twist from the throstle, or mule-twist from the mule-frame, be produced, the cotton has subsequently to be wound into hanks, which have always the same length—namely, 840 yards, or very nearly half a mile. According to the number of such hanks as will weigh a pound, the yarn is called in the trade: thus, if seven hanks were required, the yarn would be called No. 7s; if twenty, then No. 20s; and so on: so that the denomination of the yarn at once indicates its size, &c. The hanks are then made up into bundles of 10lbs. each, ready for the demand of the manufacturers of various goods; or if intended for bleaching, are sent in bales carefully packed to prevent the yarn from being injured.

Fig. 23 will afford the reader some idea of the appearance of mule-spinning. On the right-hand side, the frame is seen drawn out to its full extent; while on the left it is closed, forming the "cop" already mentioned.

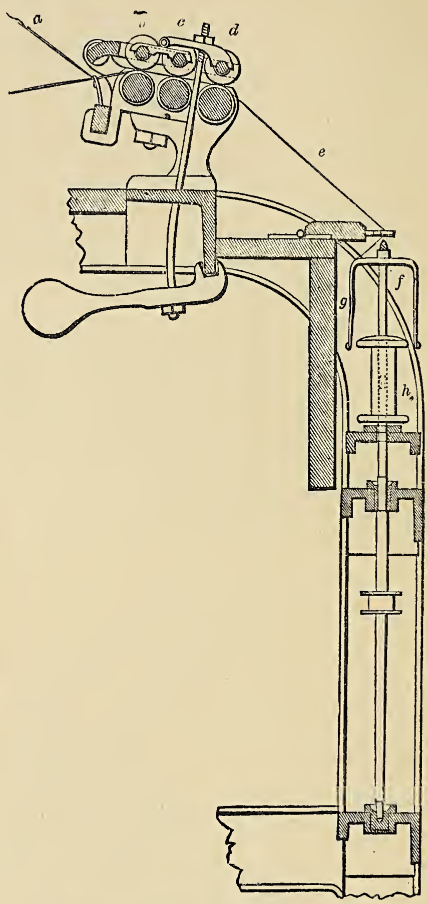

Fig. 21.—Throstle-spinning Frame.

So far we have endeavoured to give an account of the process by which cotton wool is by various stages brought into the condition of yarn. Such a description has been intended solely for the general reader, and of course a large number of details have been left unmentioned. It will be evident, however, from what has been stated, that the preparatory steps to spinning are essentially those which lay the fibres of the cotton as nearly parallel as possible, clears them of all knots and other faults, and so affords every chance of producing an even and strong yarn, no matter for what purpose this may be subsequently required.

But among our readers we presume there will be many to whom a more exact account of the present state (1881) of cotton machinery will be desirable. To suit their requirements we shall avail ourselves of a Paper read before the Institution of Mechanical Engineers at Manchester

Dr. Cartwright

by Mr. Eli Spencer, of Oldham. We are indebted for the text and for the illustrations to the kind permission of the proprietors of *Engineering*. The paper was written in compliance with the request of the President, and was intended to describe the main improvements in machinery for preparing and spinning cotton made since 1866.

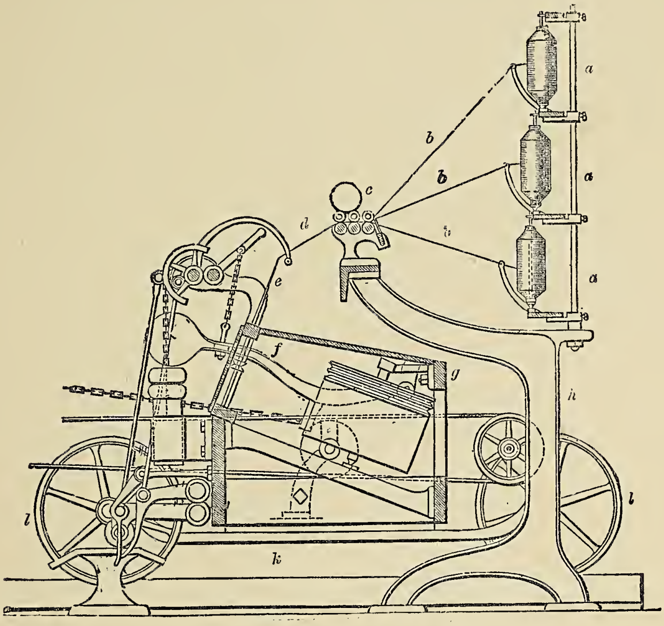

Fig. 22.—Self-acting Mule-spinning Frame.

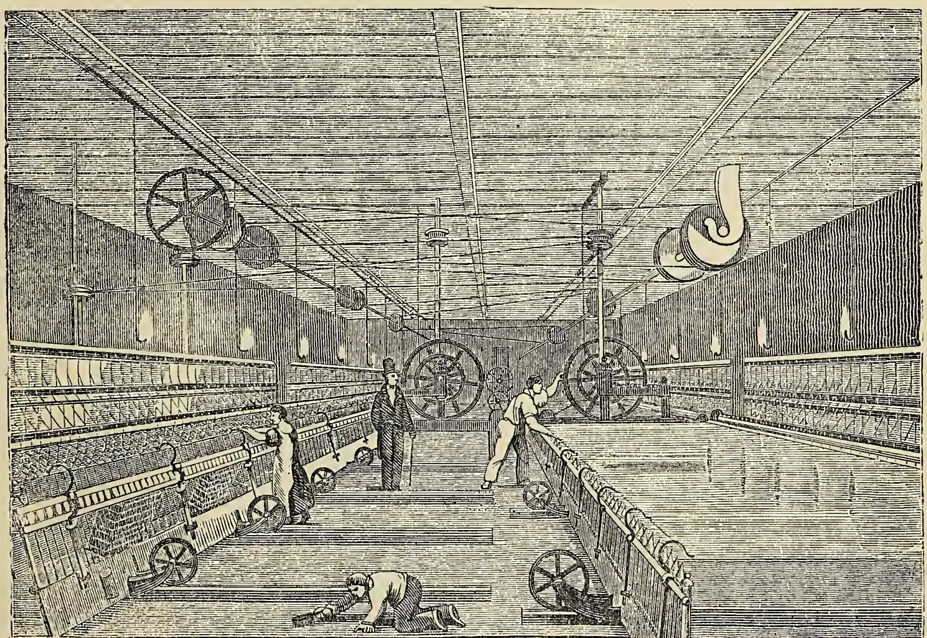

Fig. 23.—Cotton Mule-spinning.

Opening and Cleaning Machine.—Machines for opening, cleaning, scutching, and forming cotton into laps, to be fed up to the carding engines, have undergone very little change in design since 1866; but changes have been made to economise labour by shortening operations, *e.g.*, the use of single instead of double machines, and a better disposition and arrangement of the machines in the mills.

The Carding Engine.—The principal change under this head has been the supplanting of the finisher carding engine by the combing machine.

For carding cotton for coarse numbers or counts, the roller and clearer engine is still preferred; but for medium and fine counts the self-stripping flat card is much more extensively used. This is now made with a great perfection of accuracy, and supersedes to a large extent that class of labour in the cotton mill which is the most difficult to control.

Steel instead of iron wire is now more generally used for card teeth. Its advantage over iron is that it can be drawn finer, and will thus give more points in a given surface; it also admits of being hardened, and carries a finer point; while, as the hard points keep their sharpness for a longer period, less grinding is required, and the wear and tear is reduced.

The Combing Machine.—Cotton intended to be worked into the finer qualities of yarn is now generally combed, instead of being carded by a finisher card. The combing machine is thus becoming one of the most important machines in the cotton trade. On its introduction to this country in 1851, it was used for Nos. 200 to 300 only; but in recent years, owing to the demand for a better class of yarns, for sewing and other purposes, its use has rapidly extended, and at the present time numbers as low as 30 to 40 are made from combed cotton. When a clear, strong, and uniform thread is required, the combing machine is indispensable, as it completely separates the long fibres from the short ones, which the carding engine does only partially.

Cotton that is to be combed is opened, cleaned, and carded on the breaker card, and the sliver is delivered into cans. A number of these are put up behind a drawing-frame, and their slivers passed through it, to be drawn, straightened, and laid parallel. By drawing the slivers once or twice through the drawing-frame, the loops and kinks are to a great extent taken out, and less waste is made. About fourteen cans of the sliver thus made on the drawing-frame are doubled and united at the lap machine so as to form a lap $7\frac{1}{2}$ inches wide, which is then passed through the combing machine.

The machine invented by Heilmann was the first successful machine for combing cotton, and in its principal features it remains as it was originally brought out. Many attempts have been made to supersede it by Lister, Whipple, Imbs, Lacour, Heilmann-Ducommin, and others; but it has always maintained its position. Its mechanical details have however been much improved during the last ten years, in order to obtain higher speeds and greater production; and now 80 nips per minute are obtained, whereas formerly not more than 60 to 65 per minute were made. The machines are also made of greater length, viz., with eight heads instead of six, and their production has been proportionally increased, so that an eight-head machine produces 250 lbs. per week of $56\frac{1}{2}$ hours.

The improvements introduced since 1866 are as follow: (1) The machine is better constructed, many of its parts are made interchangeable, and some of them have been removed; (2) By the application of nipper cams at both ends of the machine, torsion is prevented, and a better nip is secured; (3) The machines are now made of eight to ten heads, or deliveries in length, instead of four or six; (4) All the cams for giving reciprocating motion have been set out afresh; they are now cut by machinery, and smoother action, increased speed, and greater production are insured; (5) An improved stop motion has been applied, to stop the machine in case of sliver breakage, or when the lap is run off; (6) A stop motion has also been applied to the coiler, to stop the machine in case of roller lap or when breakage of the sliver at the draw-box occurs; and another apparatus, to stop the machine when the can is full, has been introduced; (7) A motion has also been applied to give a horizontal movement to the comb brush, for the better cleaning of the circular comb.

The Drawing Frame.—The general arrangements of this machine (Figs. 1 to 5, page 24) are the same as described in the original paper, but some improvements in detail have been introduced. The bottom rollers are case-hardened, so as to resist the severe strain put upon them. The gearing for connecting the four lines of bottom drawing rollers is arranged at the driving end of the frame, so that each roller starts at the same time; this secures a more certain and uniform drawing of the cotton sliver than when the connection is made at both ends, as heretofore. It also prevents cut places in the sliver, when the frame is started after a broken sliver has been pieced. The front and back rollers are connected by a "crown wheel" arrangement; and the intermediate rollers are connected with the back roller by separate carriers, any one of which may be altered without affecting the speed of the other rollers. The wheels and pinions employed are of much larger diameter than those formerly used, and are capable of giving much finer variations in the "count" of the sliver produced. When the draft is changed, no difference is made in the intermediate or breakage drafts. The operation of changing is so much simpler that less skilled "carders" or overlookers may be employed; in the old arrangement the relationship of the several rollers was so difficult to understand that mistakes were continually being made. It was then found more convenient to change the breakage draft between the third and fourth rollers than between the first and second, *where the change however ought to be made.*

A much more substantial and convenient support is given to the gearing, as shown in Figs. 2 to 5: the drawing operations are thus made smoother and easier, and the quality of the slivers is improved. Front stop motions are now universally employed, and are made very sensitive and quick in action; a great deal of waste is thus prevented, and better work is produced. The back stop motions are also constructed to act with greater promptitude when a sliver breaks, thereby stopping the frame before the broken sliver has passed under the back roller, and enabling the piecing to be made before the end is lost (see Fig. 1).

The knocking-off motion (Fig. 1, page 24) is the apparatus by means of which these various stop motions are enabled to stop the machine. It is similar to the old one in its principal features; but it is simpler and easier in its action, and requires very little force to bring it into operation; consequently it acts very quickly, and is not liable to derangement.

At (7), Fig. 1, is an eccentric, which causes the rod to reciprocate, and at the other end of this rod is a slot inclined to the rest of the lever; between the two ends of this lever is a projecting piece (8*a*), which is capable at the proper time of lifting the bar (9) out of a notch, and liberating it. At (10) is a lever fastened to the oscillating shaft (2); and at (11) is a lever carrying a weight, which tends to move the lever and shaft (2) in the direction of the arrow (12); consequently keeping the stud (13) against the end of the slot in the rod (8), and causing the rod to pull the stud (13) in the direction of the arrow (14), when itself moving in that direction.

The action may be illustrated by the back stop motion, Fig. 1. The cotton sliver, which passes over the tumbler (15), is shown broken, and the tumbler has been liberated, which allows its weighted end (16) to drop, and so to come in contact with an arm (17) fastened on the shaft (2), and to arrest the motion of that arm in the direction of arrow (12). This causes the stud (13) to become stationary; and the rod (8) still moving in the direction contrary to the arrow (14), the inclined slot causes that end of the rod to rise in the direction of arrow (18), and so brings the part (8*a*) in contact with the bar (9), which, being thus lifted and liberated from its notch, moves the driving strap from the fast to the loose pulley.

The front stop motion is also shown in Fig. 1. At (19) is a funnel-shaped guide, through which the sliver (20) passes on its way from the front roller (21) to the calender rollers (22) and (23). The sliver passes in at the large end, and out at the small end, which is contracted until it requires a considerable pull to draw the cotton through it. The guide (19) is fastened to the end of the lever (24). The other end of this lever is heavier than the guide end, and tends to turn it in the direction of the arrow (25). At (26) is another reciprocating rod, connected with the oscillating shaft (2) by the lever (27). The other end of this rod is notched. The weighted end of lever (24), when liberated by the breaking of the sliver, falls against this notch, thus arresting the motion of the rod (26), and therefore of the shaft (2) and stud (13). This brings the stop motion into action as before described, and at once stops the machine.

A can stop motion is now used, which stops the machine when the can is full (see Fig. 1). This apparatus consists of a false bottom (3) to the coiler wheel (4). The plate forming this bottom is weighted by a ring, which is varied in weight to suit the length of cotton to be contained in the can. The finer the cotton, the larger the ring. Fine drawings will not permit of being pressed so tightly in cans as coarse ones. When the can is filled sufficiently to lift up the plate (3) close to the coiler wheel (4), a stop (1) is brought into contact with the oscillating bar (6), connected with the lever (17), and stops the machine as before described.

It is found very advantageous to put the same length of cotton sliver in each can, so that when they are placed up to the next passage of drawing, or to the slubber, they will all be emptied at the same time. By this means the attendant knows which cans require replacing without looking into more than one. When the quantities in the cans vary, the "tenter" is compelled to look well after them, otherwise the machines will very often stop. Another great objection to the old system is the liability of the can to be filled until no more can be forced into it, thus damaging the sliver and often breaking the coiler tops. By using the can stop motion the work of the tenter is more systematic, and a greater weight is got through the drawing frame, with, at the same time, a slower speed of the front roller.

The use of loose-bossed top rollers has now become almost universal for drawing frames. Another important improvement in drawing frames is the application of a patent clearer for the top rollers. It consists of an endless clearer cloth, driven positively by gearing at a very slow rate, with arrangements for mechanically stripping the same. Its great cost has, however, prevented its general adoption.

Electricity has in some instances been employed as a stop motion in these machines, with more or less success; but its adoption has been by no means general, and the limits of this paper will not permit further observations upon it.

Slubbing, Intermediate, and Roving Frames.—The improvements introduced into slubbing, intermediate, and roving frames consist of better winding apparatus, stronger spindles, steel flyers, case-hardened rollers, stopping and lock motions, &c.

On the question of the bobbin or the flyer leading, in the winding of the thread or sliver on the bobbins in these machines, there has been a great change in practice since 1866. Formerly nearly all machines were made with the flyer to lead, especially when pressed flyers were used; whereas now the demand of the trade is almost universal for the bobbin to lead. The latter arrangement increases the duty of the differential motion, and demands more perfect control of this apparatus. Hence the cones employed for driving the differential motion, revolve at

very much quicker velocities than formerly; in some cases at double, and others at treble the old rate. The cones are placed further apart, so as to give a much longer belt; thus transmitting the necessary power with less strain on the belt, and imparting more uniform winding.

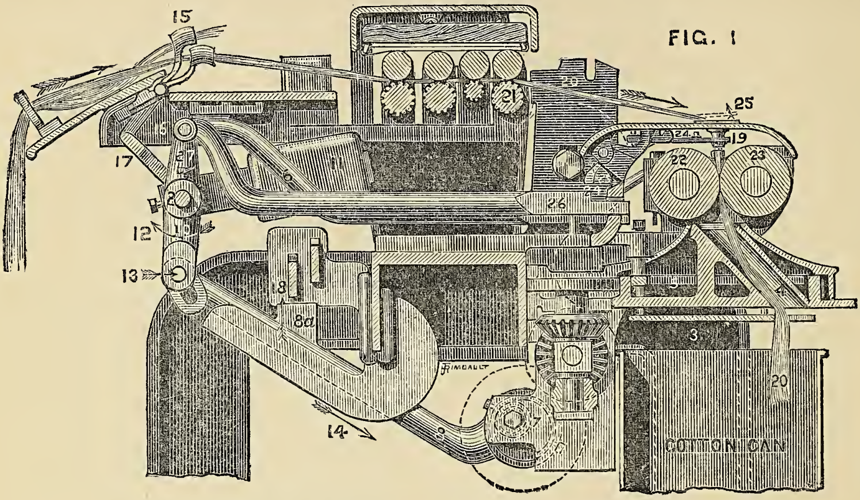

Fig. 24.—Improvements in Cotton-spinning.

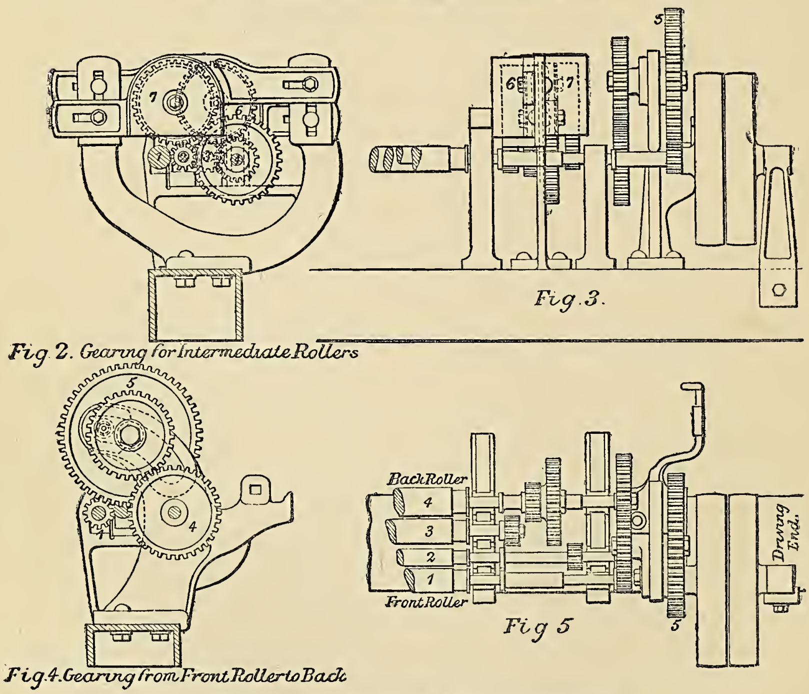

Fig. 25.—Improvements in Cotton-spinning.

In all these machines the spindles always start before the bobbins, because the connection of the spindle with the driving pulley is positive by gearing; while the power for driving the bobbin, having to pass through a differential apparatus, and not being positive, on account of the belt, cannot take up the backlash so quickly. When the flyer leads there is a tendency to stretch the roving. When the bobbin leads there is a slight slackening of the sliver, which is immediately taken up by the bobbin after it has got in motion.

Attempts have been made from time to time to dispense with cones and belts for regulating the winding of these frames, and to substitute metallic apparatus; but hitherto they have been unsuccessful.

The increased speed of spindles, and the general use of single-pressed flyers, *i.e.* with a

presser on one leg only, has rendered it necessary to strengthen the spindles, to enable them to stand the extra duty imposed upon them. A higher standard of efficiency is now required to produce the quality of work demanded by modern competition. This has done much to bring into larger use long collars or bearings, produced by the double presser upon the bobbin is a very undesirable one, and the finer the count or hank the greater the objection.

Flyers without pressers, for soft bobbins, are still used for the finest counts of yarn, and will always surpass pressed bobbins where excellency alone is desired; but the perfection of

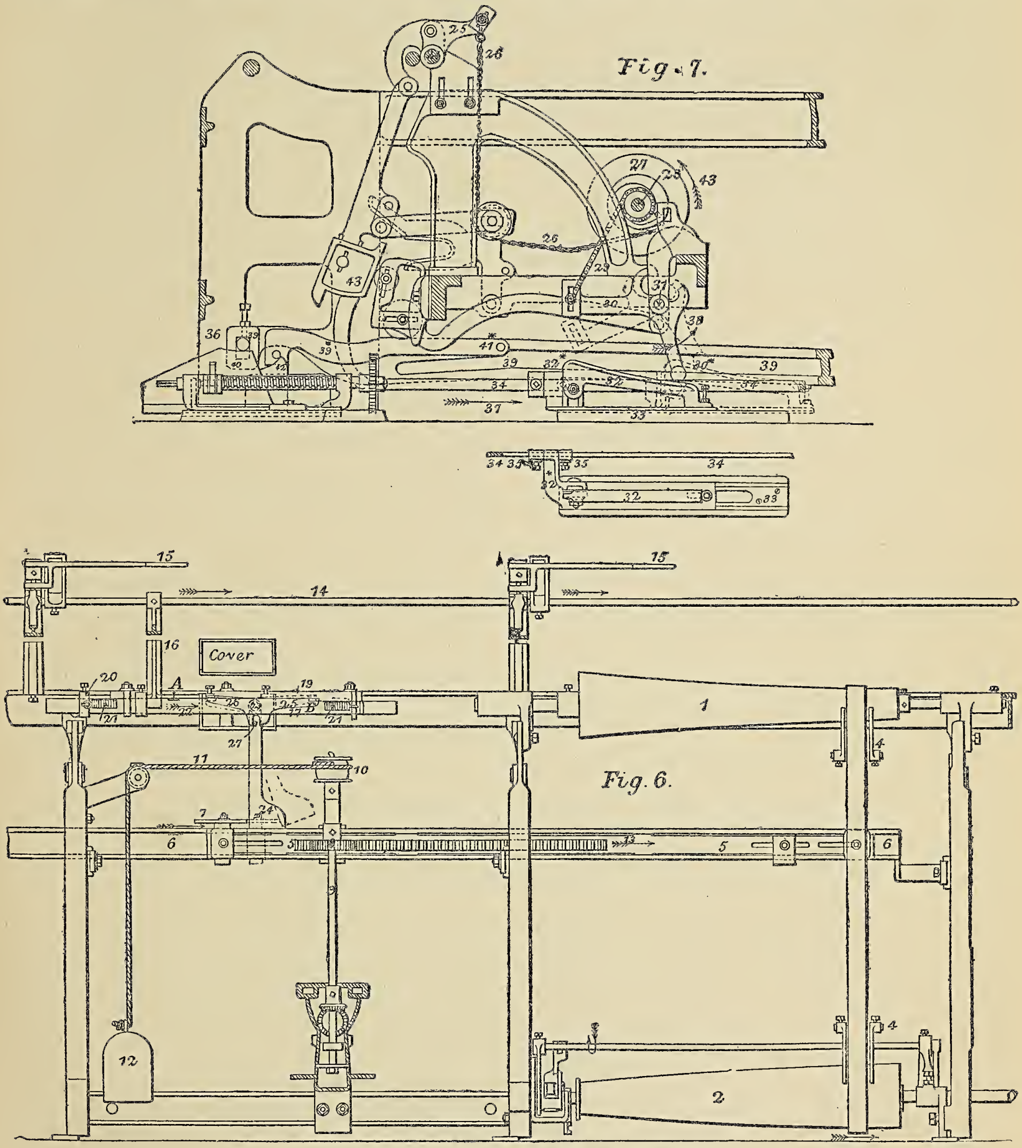

Fig. 26.—Improvements in Cotton-spinning.

to enable the spindles to stand the strain of the comparatively unbalanced single-pressed flyer. It is found in practice that nicer work can be obtained from single-pressed flyers than from double-pressed ones; this is especially true when making finer hank rovings, say above nine or ten hanks in the pound. The effect modern flyers, and the necessity of keeping down the cost of production of yarn, has caused the adoption of pressed bobbins, for even up to twenty-four hank roving. The pressed bobbin contains about double the quantity of roving, and lessens the labour of "creeling" in the after processes.

The best flyers are now made of solid steel. They are much lighter, will stand a much finer polish, and allow of being worked into shape without fear of cracks inside their hollow legs; where the slightest roughness catches the fibres of cotton, and causes the work to be badly done, and the ends of the sliver to break. Machines have long been made to stop when a sufficient quantity of roving has been wound on the bobbins. The best kind are now fitted with an apparatus (see Fig. 6, page 25), by which, after stopping, it is rendered impossible to set the frame to work again until the full bobbins have been replaced with empty ones, and all is made ready for another start. Before this improvement was applied tenters had a bad habit of setting the frame to work again, after the ordinary stop motion had stopped the frame, by holding the strap on the fast pulley, until the bobbin was as large as the flyer would permit without breaking the ends. The result was very bad work; the slivers were stretched and made very rough, and the flyer legs were often strained out of their proper position and balance.

This lock motion, shown in Fig. 6, is controlled by the rack of the cone motion. At (1) and (2) are the cones for driving the differential "jack-in-the-box;" at (3) is the belt; at (4) is a double strap guider, fastened to the rack (5), which slides in a rack-box (6). At one end of the rack is an adjustable piece (7). At (8) is a pinion fastened on the shaft (9), and gearing into the rack (5); at the top of the shaft is a band pulley (10); fastened to it is a band (11), at the other end of which is a weight (12). The weight (12) tends to turn the shaft (9) and its pinion, which causes the rack to move in the direction of the arrow (13). At the bottom of the shaft (9) is a ratchet wheel, controlled by the well-known apparatus called the "box of tricks." This apparatus allows the ratchet to turn on its axis through one tooth, at each rise and fall of the lifting rail which carries the bobbins. The rise and fall of the lifting rail corresponds in each case to one layer of roving wound on the bobbin. The strap (3) is thus gradually traversed from one end of the cone to the other. At (14) is the ordinary setting-on rod of the frame, connected to the strap guider. At (15) are the ordinary handles used by the "tenter" to start and stop the frame by; at (16) is an arm fastened to the setting-on rod (14). At (17) is a slide bar, sliding in the brackets (18) and (19), and having two notches in it, A and B. At (20) is a bracket bolted to the slide bar (17). A spring (21) (shown broken) is hooked on the bracket (20) at one end, and on the bracket (19) at the other end. This spring tends to pull the slide bar (17) in the direction of the arrow (22). At (23) is a centre stud carrying the lever (24) and the catches (25) and (26); these are loose on the stud (23). Near the boss of the lever (24) is a pin (27), which is capable of acting on the catches (25) and (26), and is shown holding the catch (26) above the slide bar (17).

The parts are shown in the position they occupy just previous to the lock motion being brought into operation. The end of catch (25) is resting in the notch B of the slide bar (17), thus preventing the spring (21) moving it. When the bobbins are full, the bracket (7) will have carried the lever (24) sufficiently with it to lift the catch (25) out of the notch B; thus relieving the slide bar (17), and allowing the spring to move it and the setting-on rod (14) in the direction of the arrow (22), and so to pull the driving belt from the fast to the loose pulley and stop the frame. The movement of the lever (24) removes the pin (27) from contact with the catch (26), and allows it to fall into the notch A of the slide bar (17), which locks the slide bar.

The catch (26) and the upper part of the lever (24) are contained in a box which cannot be tampered with; it is therefore impossible to set the frame on again, until the catch (26) has been disengaged, by winding the rack (5) back again, ready to commence for a fresh set of bobbins.

The general result of these improvements is not so much extra production per spindle—although this is greater for the same velocity of spindles than it was formerly—but a very superior quality of work, which enables the attendant to watch a greater number of spindles at the same cost. The machines now work with much less breakage, and it is no uncommon thing for a set of bobbins to be filled without an end breaking.

In well-arranged establishments it is now generally admitted that a moderate speed of spindles is most economical, and produces the best quality of work with a minimum quantity of waste. In some parts of Lancashire very high speeds of spindles are preferred; but this system, with its attendant amount of waste and inferior work, is gradually giving way to more moderate rates of speed. The well-established maxim that "work spoilt in the card-room cannot be mended in the spinning" is the best guide in this matter.

It is now customary to make very long machines what is termed "double geared," namely, with a driving part at each end of the frame. The spindles and rollers are in one continuous line from one end of the frame to the other, but each half can be stopped independently, so that when an end breaks only one half of the machine is stopped to piece the broken end, leaving the other half at work. An increase of about ten per cent. in production is gained by this useful arrangement.

For the finer grains of yarn, there are four passages of these machines,—the slubber, the intermediate, the second intermediate, and the roving or jack. These enable the required fineness of roving to be attained without involving excessive drafts, which should in no case exceed one into six.

The Self-Acting Mule.—In its general arrangement the self-acting mule remains as described in 1866, but many very important additions and improvements have been introduced. The self-acting mule of 1866, although covering the principal operations, left a number

of minor ones to the skill of the operative spinner or "minder," and it performed some of its duties in a very imperfect manner. To be in order we will first refer to mules for spinning medium counts of yarn, and secondly to those required in the spinning of finer counts of yarn.

Mule for Medium Counts.—Here the improvements are as follow :—

1. The governor motion for regulating the position of the quadrant nut has been made at once exceedingly sensitive and very reliable, and is now suitable for either coarse or fine counts.

2. The backing-off motion has been perfected, its operation being regulated automatically to suit the position of the cops at every stage of their progress, from the commencement of winding to the completed full cop. This apparatus was formerly imperfectly manipulated by the minder.

The copping apparatus is now used as the controlling agent (see Fig. 7, page 25). It is made with the front "incline" loose, and governed by a separate copping plate; formerly only two points in the copping rail were capable of being adjusted to the exact positions required; whereas by the use of the loose incline, all the positions are now regulated. The advantage gained by this latter arrangement is the power of regulating the precise position of the faller wire when the "faller" is locked—a very important consideration. In the hand mule, when the spinner had depressed the faller to the proper position for winding, and uncoiled the exact amount of yarn from the bare spindles, he arrested the operation of backing off, and commenced the winding-on operation. In the self-acting mule with the copping rail in one solid piece, this important object could not be attained. The amount of inclination in the front incline was determined by the conditions required to commence the cop on the bare spindles. It was very important to keep the "chase" of the cop as short as possible, to prevent waste in unwinding in the subsequent processes. When the copping rail was set at the commencement of the cop, the position of the faller wire was determined, and set to suit the requirements of the operation; but as soon as the winding part of the copping rail assumed the more inclined position to enable it to wind a longer chase, then the front incline assumed a less inclined position, leaving the position of the faller wire at the time of the faller lock in a worse position each draw, until the maximum chase had been attained, and the gradual shortening of the chase had begun. This was in reality a complete reversion of the practice of the hand spinner's operation. For many years this method was considered quite satisfactory; but the demand for longer cops, built more firmly, gave the impulse to the present improvement. Now, the front incline being movable, its position can be regulated so that the operation will be an exact counterpart of the hand spinner's work, when he made his best cop; and by the use of an automatic apparatus for regulating the backing-off chain, in conjunction with the loose incline on the copping rail, the amount of yarn uncoiled from the spindles is regulated to suit the position of the faller wire at the termination of the backing-off. When once set, this apparatus needs no attention from the minder.

As the copping motion was explained at length in the former paper, and as the principle is exactly the same, it is unnecessary to describe it beyond what relates to the loose "incline." This is shown in Fig. 7. At (39) is the copping rail. One end rests on the copping plate (40), and the other end of the rail rests on the back copping plate (41). At (39*) is the loose front incline, jointed to the copping rail, at the "ridge" of the rail, by the joint pin (41*). The other end of this incline rests on the copping plate (42), which is fastened to the copping plate (40) in such a manner that it can be adjusted to suit the requirements of the loose incline.

By varying the form and position of the copping plate (42), the loose incline can be regulated to give any required results. The diagram shows the faller locking arrangements, with the lock at the bottom of the lever (43), instead of, in the former arrangement, at the top. The principle is the same in both systems, the alteration being made to suit the requirements of the other parts of the headstock, connected principally with what are technically called the "changes."

The Backing-off Chain Tightening Motion.—Before explaining the parts connected with this motion, it may be desirable to give some further explanation why this regulation is required.

When the carriage is coming out, or in its outward run, the front or winding faller wire is generally about $1\frac{1}{4}$ inches above the spindle points. This is also the position of the parts, in ordinary mules, immediately before the operation of backing off. As is well understood, the reversion of the tin roller causes the tin roller to uncoil the yarn from the spindles, and also brings into action the parts which pull the faller wire down. In all cases the spindles begin to uncoil before the faller wire begins to move, because the tin roller must make some little movement before the backing-off click or pall can take hold of the ratchet wheel. In addition to this, the spindles continue to uncoil the yarn during the time the faller wire is moving from its position above the spindle points, until it touches the yarn. From this it will be seen that a considerable length of yarn will be uncoiled from the spindles, before the faller wire can overtake the yarn. The spindles thus have the start very considerably, and at the completion of a set of cops this loss of motion produces the worst results. In the case of a cop with its nose, or point, only $\frac{3}{4}$ inch from the spindle points, the loss is nearly one-half; the faller wire moving as much before it touches the yarn as it does after. To overcome this difficulty, it is necessary to have the backing-off chain tight, so that it may act on the faller as early as possible; and the backing-off snail is made as large as possible and of the proper form, so that the faller wire may rest on the yarn at the earliest moment before it locks.

At the commencement of a set of cops the conditions are very much more favourable; the space passed through by the faller wire, before it touches the yarn, being very much less, in proportion to the entire distance passed through by the wire before the faller locks, than it is at the completion of the set of cops. Consequently, the backing-off chain has to be slack at the beginning of a set of cops, otherwise the speed of the wire would force the yarn down the spindles faster than it would uncoil, and so break the thread. Hence, the backing-off chain having been adjusted to the proper length to back off nicely at the commencement of the set of cops, it is desirable gradually to tighten or shorten it, as the cop increases in length; until at the completion of the cop the chain is almost tight. By this means the backing off can be adjusted all through the set, so that it corresponds at every stage to the exact requirements of the case; the nose of the cop is preserved in a proper condition, and neither too much nor too little yarn is uncoiled. Next to winding the yarn properly on the cop, this is the most essential condition in making a good cop. Where the apparatus now to be described, which affects this automatically, is at work, it is found that very much fewer "noses," or points of cops, are "halched," or entangled.

Referring to Fig. 7, page 25, at (24) is the winding faller shaft, and at (25) is the backing-off finger; at (26) is the backing-off chain, fastened at one end to the finger (25), and at the other end to the backing-off snail (27), mounted on the tin roller shaft (28). At (29) is the backing-off tightening chain; one end of it is fastened to the boss of the snail (27), and the other end is fastened to the lever (30), mounted on its centre stud (31). The other end of this lever (30*) is shown resting on an incline (32). This incline slides and rests upon a plate (33) fastened to the floor. At (34) is the copping plate connecting rod. An arm (32*) of the incline (32) grips the rod (34), and, by means of two hoops (35) fastened to the rod (34) by set screws, the incline bracket (32) is caused to move with the motion of the rod during the formation of the cop.

Fig. 7 shows the positions of the carriage and the various parts just previous to the time of the backing off taking place, at the commencement of a set of cops. The backing-off chain having been adjusted to the proper length for backing off on the bare spindle, the copping plates (40 and 41) and the rod (34) will gradually move, as the cop progresses, in the direction of the arrow (37), and carry the incline (32) with them in the same direction. This movement gradually brings the higher part of the incline (32) under the tail of lever (30*), causes it to turn in the direction of the arrow (38), and pulls down the chain (29); which, acting on the snail (27) turns in the direction of the arrow (43*). This movement of the snail (27) takes up the slack of the backing-off chain (26). The incline (32) is made so that it can be varied to suit the particular requirements of various kinds of mules. The absolute amount of tightening depends upon the setting of the incline; and the ratio depends upon the form of the incline. By varying the form of the incline the action on the chain can be varied to suit any circumstances.

When once set the apparatus needs no further attention. At the commencement of a new set of cops the copping plates are wound back, the incline (32) goes with them, and the backing-off chain is restored to its normal position.

The Automatic Nosing Motion.—An important addition to the mule in late years is an improvement applied to Richard Roberts's quadrant winding apparatus. In Roberts's quadrant, as first introduced, the only variation in its action, when once set in proper position, was caused by the position of the "nut" on the screw being changed to suit the increasing diameter of the cop, until this had attained its full dimension, when no further modification was made. Now if the spindle blades had been of equal thickness throughout, the winding on would have remained in all its stages equally good; but this is not so; the spindles are taper.

The function of the quadrant is to accelerate the velocity of the winding motion, and this constitutes its special merit. The amount of this acceleration begins at zero, and the velocity ratio is governed by the distance of the quadrant nut from the centre of the quadrant, at any moment during the building of the cop, until it arrives at its full diameter. It thus conforms very nearly to the true requirements of winding. When the cop arrives at its full thickness, no further alteration in the position of the nut takes place; and there is no further alteration in its velocity ratio.

As all cotton mules have taper spindles, it was soon found that the "cop noses" could not be wound tight; and as a longer cop requires a longer and stronger spindle, and therefore an increase in the amount of taper, the points of the spindles being always the same diameter, this difficulty has increased as the spindles are made longer. To put this more clearly, it will be well to describe the whole operation, its requirements, and what has been done since Roberts's time to meet this difficulty.

The winding parts of a mule should be made so that when the quadrant nut is at the bottom of the quadrant (that is, near its axis), the mule can wind the first stretch of yarn on the bare spindle, without either leaving yarn uncoiled on the spindle, or winding it on too tightly, and so breaking the ends. This is the ordinary condition; but for special cases, such as when winding the yarn on paper tubes, &c., this rule is departed from. This does not however affect the purposes of the explanation. As the cop bottom increases in diameter the quadrant nut is raised to suit it; thereby decreasing the speed of spindles when they are winding on the larger diameter of the cop, but imparting the full terminal speed to the spindles when the carriage completes its inward run. This final speed is the same as the velocity when commencing on the bare spindle. Now the blade of a cotton mule spindle tapers from about $\frac{1}{3}$ inch in diameter, to $\frac{1}{16}$ inch in diameter; and as it is

necessary in a well-built cop to wind the nose of the cop in all its stages equally close and firm, it follows that the winding must be gradually modified, so that the velocity of the spindles at the termination of the inward run of the carriage shall be suited to the diameter of that part of the spindle on which the nose is being formed. That is to say, the terminal velocity of the spindles should increase in the same ratio as the diameter of the spindle decreases. This acceleration or "nosing," as it is called, takes place when first brought into action, almost at the termination of the inward run of the carriage; and begins a little earlier at each draw or run, until at the finish of a set of cops the "nosing" may begin 5 inches or 6 inches from the end of the inward run of the carriage. If the nosing begins too soon, the yarn is wound too tightly on the part not requiring assistance, and is unduly stretched. This is very plainly shown by the action of the counter faller, which is pulled almost close to the winding faller, and then, when the nosing is required, is seen to rise. This action is most injurious to the yarn.

To meet these requirements many contrivances have been invented during the last fifty years. The one most generally in use is that called the "nose peg." This nose peg, acting on the winding chain, deflects it from a straight line into a bent line, causing additional chain to be uncoiled from the winding-on drum, and consequently increasing the velocity of the spindles. This, although an improvement, imparts but little acceleration, and the little it does begins too early; say about 18 inches from the end of the inward run of the carriage. Various forms have been given to the nose peg, but all amount to the same thing in practice.

The next important improvement was brought out in 1863, and consists in making the nose peg bracket into a swing lever mounted on the quadrant. By giving this lever a movement on its centre, its action on the winding chain is quickened, the acceleration of speed is greater than it is with the fixed nose peg, and its action may commence much later. But the nosing, even with this swing lever nose peg, commences too early, is limited in action, and appears to lose its accelerating function when it ought to be greatest. This is true of all nose pegs, whether worked by hand or self-acting.

Nearly all nosing motions invented during the last fifteen years have been modifications of the swing lever, and all except the scroll drum nosing motion are chain deflectors. What is wanted is something which shall continue or supplement the ordinary velocity-accelerating function of the "quadrant," so that its action will be suited to the constantly diminishing diameter of the spindle on which the cop nose is being wound. This object is attained by the application and use of a scroll on the end of the winding-on drum.

When the cop has attained its full diameter, the scroll drum should be in the position shown in Fig. 9 and Fig. 10, page 32. As the cop is gradually built up, more winding chain ought to be uncoiled from the scroll, until, at the completion of the cop, the chain should be uncoiled, as shown in Fig. 11, page 32. It will be understood that the velocity of the winding increases in the same ratio as the diameter decreases of the scroll from which the chain is uncoiled. The amount of acceleration thus given depends on the quantity of the scroll part used; and the character of the acceleration depends on the form of the scroll end of the winding drum. Its range of acceleration is very much greater than in any other apparatus yet invented.

Figs. 8 to 11 (page 32) show the apparatus. Fig. 8 shows the position in which the parts should be placed to commence with. The quadrant is shown in the position where it stands when the bowl is on the ridge of the copping rail. The carriage is shown close up to the back stops, that is to say, at the end of its inward run.

Fig. 9 shows the quadrant nut, with the parts on it in the same position as shown in Fig. 10, that is, when the cop bottom has just been completed. The carriage is shown close up to the back stops. The quadrant nut (1) is at its final position for making the rest of the cop. The arrow on the winding-on drum is in the position shown in Fig. 8; that is, the chain has been uncoiled from the cylindrical part of the winding-on drum, until it is on the point of uncoiling from the scroll part. The arrow crosses the drum where the circular and parallel part ends and the scroll begins.

Fig. 11 shows the position of the parts at the completion of a set of cops. It will be observed that the winding chain is shown as uncoiling from the small end of the scroll.

The several parts are as follows:—At the bottom of the quadrant at (1), Fig. 8, is the quadrant nut in its proper position for winding on the bare spindle. At (1*) is shown the same quadrant nut in the proper position for winding the full diameter of the cop, and with the parts mounted on it in the position they are at the completion of the cops. At (2) is the scroll, to which is fastened the chain (3); the other end of this chain, after passing round the pulleys (4), (5), and (6), is fastened to the sliding bracket (7), which slides on the shaper screw of the copping motion (8). The action of the chain (3) causes this sliding bracket to press against the "front nug" (9) of the shaper frame which carries the shaper screw. The shaper screw is turned as usual by the ratchet wheel (24), which is moved through one tooth at each lift of the quadrant by the wire (25). The bracket (7) is so constructed that the nut (10), running forward on the shaper screw, can come into contact with it, as shown in Fig. 10, page 32, and cause it to slide with the forward movement of the nut (10), and so gradually pull the chain (3) in the direction of the arrow (11). The adjustable piece (12) is for the purpose of regulating the time when the nut (10) of the shaper plate shall come into contact with it. At (13) are two detent catches which enter into the teeth of the ratchet wheel (14) on which the winding chain is coiled. At (15) is a lever swinging on its centre stud in the bracket (16)

This bracket is fastened by a special bolt, which also serves as a bolt for holding the guard covering the quadrant pulley. At (17) is a swivel lever carried by the lever (15). The lever (17) is free to turn in the direction of the arrow, but not in the contrary direction. At (18) is a bracket fastened to the arm of the quadrant. This bracket is capable of pushing back the lever (15) by means of the lever (17), when the quadrant is turning in the direction of the arrow (19). The steel end of the winding chain which goes into the quadrant nut, is about 3 ft. long, as shown at (20). The curb part of the chain will therefore be shorter than usual, and no part of it passes under the anti-friction bowl into the quadrant nut; by this means the wear of the chain in passing round the small pulley is entirely prevented.

The parts being properly adjusted, the mode of working is as follows:—After the first stretch, the governor motion from time to time moves the quadrant nut further from the centre of the quadrant, so as to adjust the winding to the increasing size of the cop. By this movement of the quadrant nut the slack in the chain (3) is soon taken up. After the slack is taken up, the further movement of the quadrant nut causes the chain (3) to pull the lever (15) in the direction of the arrow (22). On the return of the carriage, the bracket (18), acting on the lever (17), forces it back again, and in doing so pulls a length of chain from the scroll (2), which causes it to turn on its axis and wind on the ratchet (14) a length of winding chain, which would otherwise remain coiled on the winding-on drum. By this means the length of chain left on the winding drum at the end of each stretch will remain nearly the same, until the cop has attained its full diameter, when the parts should be in the position shown in Fig. 10, page 32. Till this stage the bracket (7), Fig. 8, page 32, will still rest against the nug (9) of the shaper frame. About this time the nut (10) of the shaper will come into contact with the sliding bracket (7), will gradually draw the chain (3) and lever (15) along with it, and, as before explained, will draw a further length of chain from the scroll (2), wind up a further length of winding chain on the ratchet (14), and cause it to unwind from a portion of the scroll part of the winding-on drum (23). The repetition of this action gradually brings the scroll part of the winding-on drum into use, until at the completion of the set of cops, Fig. 11, page 32, as much of the scroll part has been brought into use as the circumstances of the case require. By causing the nut of the shaper screw to act sooner or later on the bracket (7), a greater or less amount of the scroll of the winding-on drum may be brought into use. At the completion of the set of cops the scroll (2) should be in the position shown in Fig. 8 at (1*). Before beginning a fresh set of cops the winding chain must be uncoiled from the ratchet (14).

By these arrangements the winding can be accommodated to any form of spindles.

A further improvement in the winding motion has been effected by a change in the manner of engaging the click and click-wheel on the tin roller shaft. Formerly the movement of the carriage at the commencement of its inward run, by means of the quadrant chain, drum, wheels, pinion, and click-plate, caused the said click-plate to turn on its axis, and carry with it the click-catch, which, by means of the click-spring, caused the click to engage the teeth of the ratchet wheel. As the carriage moved further on some occasions than on others before the click-catch could engage the teeth (owing to the teeth not being always in the same relative position to the catch), this caused the winding to commence in some draws earlier than in others. This was very objectionable, because the yarn would be very liable to form into "snarls" when the winding commenced later than it should have done.

To remedy this defect the click can now be engaged (see Fig. 12, page 36) before the carriage begins its inward run, by a very simple contrivance; consequently the same amount of motion is imparted to the spindles at each stretch after the cop has attained its full thickness, except what little it gains by the acceleration due to the nosing motion, as already explained. For this purpose, the boss (1), on which the click spring rotates, instead of being as hitherto a portion of a fixed bracket, is now a part of a lever (2), which swings loosely on the tin roller shaft (3). This lever is actuated at the proper time by a small bracket, screwed on the connecting rod (4), which lifts the "holding-out catch" (5). This rod receives its motion from the taking-in lever, as it puts the taking-in friction into gear. By this means the winding is more uniform in its action, the yarn is subjected to less strain, and it is kept freer from snarls.

The "middle drawing-out apparatus," for increasing the steadiness of the mule carriage, consists of an extra "drawing-out scroll" on the back shaft, opposite the middle of each half of the carriage; from each of these scrolls a band is connected with the carriage, in the same manner as at the middle of the headstock, and at the out-ends of the mule, except that for convenience the bands are here passed under the carriage. By means of these bands the carriage is governed at five points in its length.

Another important improvement in the back shaft is the connection between it and the taking-in scroll shaft. Formerly the carriage was pulled in from the headstock only, that is to say, from the middle of its length only, and the ends of the mule were kept something like parallel with the middle parts by means of squaring bands. By connecting the back shaft, when the mule is going in, with the taking-in scroll shaft, by means of extra scrolls and bands, the back shaft receives a motion exactly similar to that imparted to the middle of the carriage. It is converted into a taking-in as well as a drawing-out shaft, and the motion of the carriage is kept steady by six hands instead of two, as formerly.

The cam shaft of the headstock still retains its important position as one of the main features of the self-acting mule. In its best form it is worked by a friction box, which permits of the

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quickest velocity of rotation, and at the same time, whilst it is sufficiently positive for the work it has to perform, is not liable to break the connected parts in case of derangement. For medium counts it is now almost universally used with two changes; the other changes in the action of the mule being effected without its intervention. Thus the two former systems are combined, namely, that system in which all the changes were made by the cam shaft, and that in which no cam shaft was used. The great desideratum is reliability and rapidity; and these have thus been attained to a remarkable extent, yielding a regularity of production week by week unknown in former periods.

The general parts of the mule have been much strengthened. Rim shafts now revolve at as high an average speed as 650 revolutions per minute, driven by 4-inch and $4\frac{1}{4}$-inch belts. The pulley being 15 inches in diameter, or 3·92 feet in circumference, this gives 2,548 feet per minute as the speed of the belt; and in some cases it is even higher than this.

The backing-off, taking-in, and cam frictions have been enlarged to give them greater controlling power. The rods, levers, and various connections have been strengthened, to enable them to distribute properly the great increase of power represented by the breadth and speed of the driving belt. The winding parts and faller work of the mule have also been very much strengthened.

Spindles are now made capable of revolving at very much higher velocities; it is very common to drive them at upwards of 8,000 revolutions per minute, with cops on them 20 per cent. heavier than those formerly made.

Mules, as machines, work very much more steadily and quietly, and are far less subject to stoppages from breakdowns than before; whilst their capacity to stand the strain of the extra quantity of work produced is very much superior.

The present construction may be expected to be more durable than any constructed previous to 1866. The production of 32s yarn in 1866 was given in a former paper as $22\frac{1}{2}$ hanks per spindle per week, but some of the best mills were then obtaining 24 hanks. The present production of a modern mill, working $3\frac{1}{2}$ hours less time per week, is fully 27 hanks per spindle for the same counts, being an increase of at least $3\frac{1}{2}$ or 4 hanks per spindle per week. Indeed, the reduction in the time worked is really greater than $3\frac{1}{2}$ hours, because it was formerly the custom to clean the machinery after the engine had stopped, whereas now it is usual to clean it during the mill hours. The actual increase is equal to about 14 per cent.; but, taking the reduction of time, 6·6 to 7 per cent., into account, the increase of production is equal to about 22 per cent., whilst the quality of the yarn spun has improved from 8 to 10 per cent. as to strength.

The size or length of mules remains about the same, but the number of long mules now working has very much increased.

The number of workpeople required for a pair of mules containing, say, 2,000 spindles, is the same as before. The cops are made so much larger that fewer "doffings" are required for the same length of yarn, but taking the increased production into consideration, the actual amount of "doffing" labour is about the same.

The headstock being much improved in its automatic movements, the "minder" can devote his attention almost exclusively to piecing ends, and looking after the younger piecers.

The great velocity now given to the rim shafts has caused the line shafts of spinning mills to be driven very much more quickly; formerly 180 to 200 revolutions was considered a good speed, but with quicker rim shafts 240 to 250 revolutions is now desirable, so as to avoid the use of large drums on the line shafts, and also of large drums and small pulleys on the countershafts. Nearly all mules are now driven by countershafts.

The difficulty of obtaining these high velocities by direct driving has led to the introduction of belt and rope driving in many of the cotton mills recently built; and the results are very satisfactory, a steadier motion being imparted to the machines. The adoption of belt and rope driving has also been influenced by the number of breakdowns in the mills built during the last seven years, where gearing was used. No doubt the greatly increased production of the machines has had much to do with these accidents. Where rope or strap driving has not been introduced, cast-steel wheels have been generally substituted for the broken cast iron ones.

For spinning yarns of medium fine counts, say up to 90s, the self-acting mule has now almost entirely superseded the hand mule. The mule just described is used for the purpose, but it is supplemented by a jacking, and a roller delivery motion. The work produced is excellent, both in quality and in quantity.

Jacking Motion.—This continues the outward run of the mule carriage after the rollers for drawing the cotton have ceased to revolve, in order that any thick places which may be in the yarn may be made uniform with the rest; its effect being that wherever there is a thin place in the thread, the greater portion of the twist runs into that part first, and thereby renders it more difficult to be elongated than the thicker parts, which are thus drawn down. The amount of jacking introduced varies from zero to 4 inches or 5 inches, as the staple of cotton to be spun is longer or shorter in its length; the longer admitting of the greatest amount of jacking. Various systems have been applied for this purpose, but that known as the "sun and planet" system is undoubtedly the best, as the stoppage of the rollers is more gradual by this than by any other. As little twist as possible is put into the yarn before the jacking commences, only just sufficient to keep the fibres united; therefore, a great amount has to be put in after the rollers have stopped. This has the effect of tightening the yarn, and unless the tension is reduced the yarn is liable to break before the required amount of twist has been put in. Formerly it was customary to cause the carriage to move inwards

a little, to ease the tension of the yarn; this had the desired effect, but it shortened the stretch, and the carriage being a large apparatus, was difficult to regulate. Now, instead of moving the carriage, the rollers are made to revolve, and to deliver, at a rate which can be varied at deliver a little sliver during the inward run of the carriage, and whilst the spun yarn is being wound on the spindles. The amount varies from 3 inches to 4 inches; consequently a mule of 60 inches stretch will wind on the spindle at each stretch about 63 inches of yarn. The

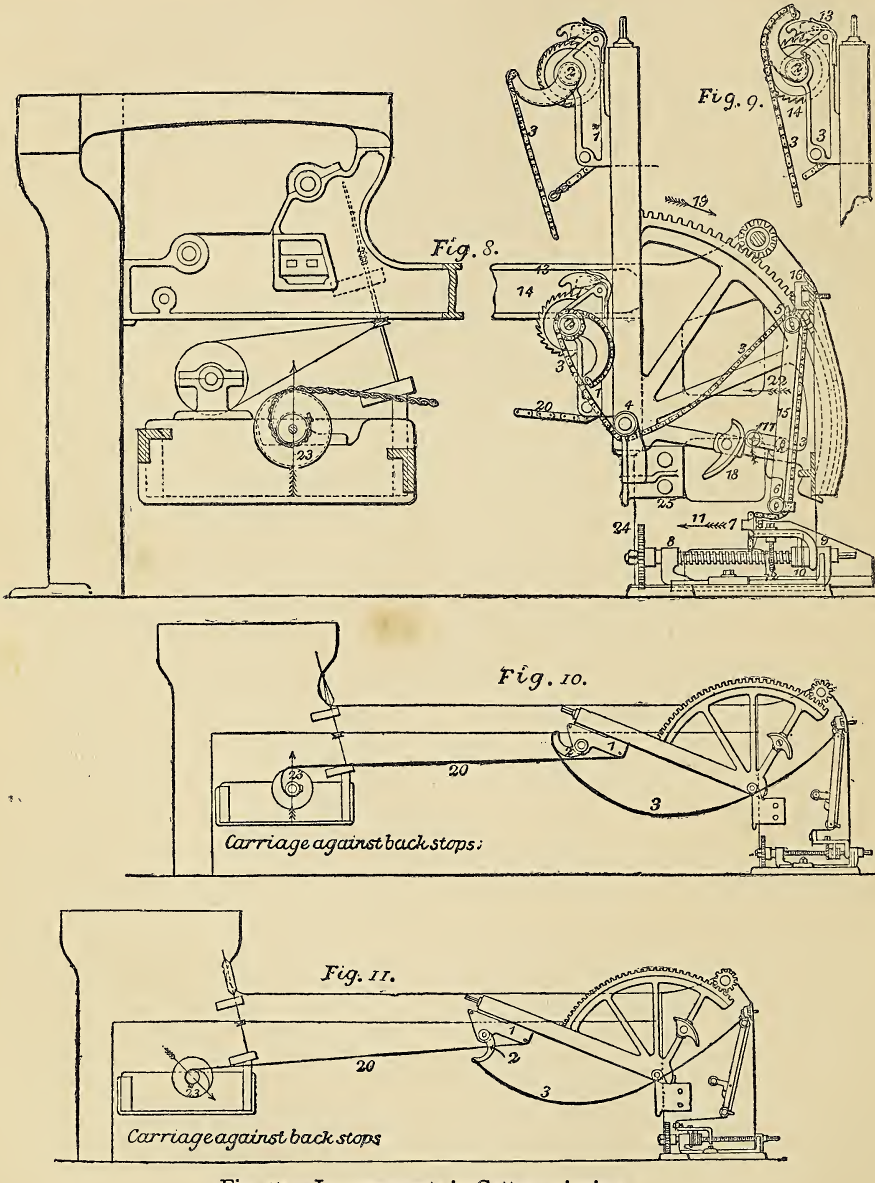


Fig. 27.—Improvements in Cotton-spinning.

will, a small quantity of roving, whilst "extra twist" is being put in the yarn; and the result is very satisfactory. This apparatus is called the "roller delivery motion whilst jacking."

It is also customary to cause the rollers to apparatus for this purpose is universally used when spinning long-stapled cotton, and the spinning is greatly improved thereby. Space does not permit to explain this more fully, or to enlarge on the drawing rollers of mules, and the varieties of spindles suitable for special yarns.

Mules for Finest Counts.—For spinning the finest counts of yarn the hand mule has been brought to great perfection; all its operations being now automatic, or nearly so. The "spinner," as he is called, has only to supply the little power required to control some of the motions. This he is able to do easily, even when the mules are large; but it requires close attention on his part, coupled with an extremely sensitive touch, which can only be acquired by long practice. To back off, wind, and lift the faller at the termination of the inward run of the carriage, in first-class style, demands great skill on the part of the operator. The work being done in hot rooms increases the difficulty, and it is almost impossible for him to work uniformly from morning till night. Men of first-class ability as spinners become scarcer year by year: and the necessity of reducing the cost of spinning has called special attention to the question of making this mule entirely automatic. During the last twenty-five years many patents have been taken out, and many schemes have been tried, but the general results have been very unsatisfactory. They were generally of too provisional a character.

The limits of this paper only admit a description of one system, which has been extensively adopted. The aim of the inventor has been to imitate the operation of the hand spinner in every delicate operation, as far as "positive" mechanism could be made available.

Description of the Mule.—The hand spinner when backing off brings the winding faller down upon the yarn, before he reverses the spindles so as to uncoil the yarn from them; and the moment the faller touches the yarn both motions act together. To obtain this result with the self-acter, the winding faller is depressed by the arm (1) and incline (2) (Fig. 14, page 37), just before the carriage completes its outward run. At the same time the slack in the backing-off chain, caused by this movement, is taken up by a modification of the apparatus used for regulating the backing-off chain, as previously described. The backing-off snail (27), chains (26) and (29), and lever (30), remain as shown in Fig. 7 (page 25 *ante*). At (5) is a lever mounted on the stud in the bracket (6); the other end of this lever is curved, and forms an incline for acting on the lever (30). At (7) is a sliding incline connected to the rod (34). The function of the curved end of lever (5) is to take up the slack chain given by the depression of the faller. The function of the incline (7) is to regulate the position of the lever (5), so that it may give the exact amount of motion required at each stage of the cop's progress. The eccentric pulley (4) is to modify the backing off, so that it may be suited to the form of the spindles. The depression of the winding faller is uniform all through the formation of the set of cops; but the position of the locking lever (3) and its parts is constantly varying within small limits, therefore a compensation is required, which is provided for by this modification. By these means a very delicate action in the backing off is obtained. The finer the counts of yarn to be spun, the slower is the velocity of the spindles when backing off. The yarn having been backed off from the bare spindle, and the faller "locked," it is now necessary to wind it on the cop, beginning at the point and winding it down to the base of the cone, preparatory to winding it from the base of the cone to its point or nose.

We have now to describe a special apparatus introduced into the quadrant motion to perform this operation in the fine spinning mule. It must be explained that fine yarns are generally doubled after being spun; and for this purpose the cops are mounted on steel skewers and placed in the creel of a doubler, in slightly inclined positions, free to turn in the creel, and allow the yarn to be uncoiled from the skewer. When the yarn is unwinding from the small part of the cop down to its full diameter, the action goes on all right, because there are many turns of yarn to uncoil, and the cop turns on its axis more slowly as the diameter increases. About 50 inches of yarn are uncoiled when the full diameter is reached; but in uncoiling the next 10 inches of yarn there is a great increase in the speed of the cop, resulting from suddenly passing from the full diameter to the small diameter at the point of the cop. This causes the cop to be jerked round too quickly; it then overruns itself, and is very liable to break the yarn. The hand spinner can regulate the number of coils at pleasure, and in practice it is found that about six coils are sufficient to give the necessary results; but to arrange this by self-acting means is very difficult, and only one solution has been found for it.

The quadrant motion, as originally used, is capable of giving an accelerating motion only; but the true requirements of the case demand that the motion shall be first a diminishing and then an accelerating one, because the winding in all cases commences on the smallest diameter, then winds down to the largest diameter, and then again back to the smallest diameter. In practice, however, this has never been fully attained. It is found that by means of the counter faller a compromise is made between the demands of the small and large diameters; and as this is only the initial stage of the winding, no harm is done, because there is a compensation in the rest of the winding which is regulated to suit the exact requirements of each stretch. By the ordinary arrangement of quadrant, it is impossible to give more than $4\frac{1}{2}$ turns of spindle during the time it is winding from the point of the cop to the base of the cone. The front incline of the copping rail has been lengthened to 15 inches, and in some cases to 18 inches, under the impression that this quantity of yarn would be wound on the spindles. It is not from this, however, that the defect arises; it is simply from the want of a sufficient number of turns in the spindles. If a long incline is used, the result is that the counter faller rises very high and takes up the slack yarn which ought to have been coiled on the spindles; and when the spindles receive the necessary amount of motion it is found that 10 inches or 12 inches of incline is sufficiently long to enable

six or seven turns of yarn to be coiled on the spindles during the putting down of the faller.

As already explained, the quadrant is governed by a grooved rope drum or scroll (26) (Fig. 8, page 32), on the quadrant shaft (27). Ordinarily, this scroll is a parallel one, and receives its motion from the carriage. If the motion of the carriage is uniform, the rotation of the scroll shaft is uniform, and the motion of the quadrant is uniform also. If at the commencement of the inward run of the carriage the relative speed of the quadrant, in the same direction, was to be reduced, it is evident that more chain would be uncoiled from the winding-on drum, and more motion would be given to the spindles. This is accomplished by making the scroll (26) on the quadrant into a variable one, the two ends being considerably larger than the middle part, which remains as before. When the carriage begins to move inwards, it uncoils the rope from the large part of the scroll (26), and consequently imparts a slower motion to the quadrant shaft (27), and to the quadrant; hence the necessary number of coils of yarn can easily be coiled on the spindles during the going down of the faller. By the time the large diameter is reached, the band begins to uncoil from the parallel part of the scroll, and no further modification of the winding motion takes place until the nosing motion comes into operation. When once adjusted, no further attention is required by the attendant. Old spinners have long declared it impossible to attain this by automatic means.

To enable the counter faller to act quickly without straining the yarn, its shaft is now mounted on anti-friction pulleys, and this is found to work advantageously. The hand spinner could wind the yarn on the cop without moving the counter faller; but for reasons already explained, this is impossible by the self-acter, the counter faller playing a very important part in the winding, etc.

Special arrangements are used in the "couplings" of the winding and counter fallers, and in the position of the counter faller relative to the winding faller, but these cannot be dwelt upon here.

The Faller-Lifting Motion.—The carriage having arrived at the termination of its inward run, it is necessary to lift the faller, and coil the remainder of the unwound yarn on the bare spindle, preparatory to commencing the spinning again. This is the most important operation performed by the spinner. He allows the carriage to arrive at the end of its run before he begins to lift the faller; the spindles and rollers are then in their nearest position, consequently there is the shortest length of yarn left to be coiled on the spindles. The relative position of the spindles and rollers, as well as the angle of the spindles to the rollers, varies with the counts spun, within well defined limits; the finer the counts the greater the inclination of the spindles to the rollers, and the more obtuse the angle made by the spindle and thread just at the commencement of the outward run of the carriage.

The winding on of the yarn requires to be regulated so that just sufficient yarn is left to coil on the spindles without either stretching the yarn, or leaving it slack to run into snarls. This is the problem to solve. The spinner having regulated the winding during the run in of the carriage, so that the proper amount of yarn was left to coil on the bare spindle, brought the operation to a stand, and then slowly lifted the faller; at the same time he regulated the winding so that the yarn was coiled on the taper spindles. As soon as the faller was free from the yarn, he allowed the mule to start again for another stretch. He performed these operations with more or less rapidity, according to the counts to be spun. On the medium counts the movements followed each other almost with the same rapidity and regularity as in the ordinary self-acting mule, but as the counts become finer the division of the operations become more marked and deliberate. This is especially so in the "box organ hand mule," in which the spinning does not commence until it is set in motion, after the completion of the faller lifting. The momentum of the various parts is completely under the control of the spinner, and is practically destroyed.

In ordinary self-acters the "unlocking" of the faller takes place during the run in of the carriage, but at as late a period as possible. The carriage, when near the termination of its inward run, brings the end of the locking lever in contact with the fixed unlocking bracket, and forces the locking lever out of contact with the copping parts of the mule. After the faller is thus unlocked, the copping rail has no further control over the faller.

It will be understood from the preceding explanation that the unlocking must be completed before the termination of the inward run of the carriage. In determining how late it is safe to unlock the faller, allowance has to be made for the variations of the speed with which the carriage goes in, owing to the variations of the speed of the engines, and to the condition of the taking-in bands, which affect the momentum of the various parts, sometimes causing the carriage to go against the back stops very heavily, and at other times scarcely to touch them. This variation affects the unlocking very materially, and causes the faller to be unlocked irregularly. In well-constructed mules these variations are reduced to a minimum, but they are never entirely eliminated. The result is that more slack yarn is left unwound than is required to coil on the spindles.

In the apparatus shown in Fig. 13, page 36, the operation is effected in the following way:—Instead of the unlocking bracket (14) being a fixture, as ordinarily used, it is mounted on a sliding bar (15) connected with a weighted lever (16). Suitable arrangements are made for restoring this apparatus to its normal position after it has unlocked the faller. When in position for unlocking it is held by a catch (17); this catch is liberated by the carriage at the proper time, but always near the termination of its outward run. The locking lever (18) and its connected parts remain as usual. The unlocking bracket is set so that the carriage can go close up to the

back stops without unlocking the faller; but the carriage no longer directly forces the unlocking. On liberating the catch (17), which holds the sliding bar on which the unlocking bracket is mounted, the weighted lever (16) falls, and forces the bracket in the direction of the arrow (19) against the end of the locking lever, and thus unlocks it just as the carriage completes its inward run. By disengaging the slide bar sooner or later the faller can be unlocked at the proper time. In practice it is found that the rollers and carriage motions are engaged, ready for another stretch, before the faller has left the yarn as it is coiling on the spindles. By these means the "winding on" is carried to the latest period, preparatory to coiling the yarn on the bare spindle.

In the ordinary self-acter, as soon as the faller is unlocked the yarn is allowed to be coiled on the bare spindle by the momentum acquired by the spindles during the run-in of the carriage, the faller wire being moved quickly out of the way by the lifting springs. The results are very irregular; sometimes snarls are wound on, and sometimes the yarn is stretched or "cut" as it is called.

In the arrangements illustrated in Fig. 13, p. 36, the tin roller which drives the spindles is connected with the faller shaft positively by a train of gearing, so that the tin roller controls the motion of the faller during its rise.

The relative motions of the tin roller and faller are not always the same. The motion of the tin roller being assumed as uniform, the motion imparted to the spindles will be uniform also; but in order that the yarn may be guided so as to coil nicely on the spindles, it is obvious that the faller wire must rise most quickly when winding on the largest diameter of spindle, and the rate must gradually diminish as the spindle decreases in thickness, thus producing a tapering spiral of yarn on the spindles. To obtain this result a pair of volute wheels are employed, which convert the uniform motion of the tin roller into a variable motion in the faller shaft.

This connection of the tin roller and faller shaft is only possible during the lift of the faller, because the tin roller, when set in motion to turn the spindles for lifting the faller, continues in motion until the backing off takes place; whereas the faller must stop almost immediately it has coiled the yarn on the bare spindle.

The following is the mode of action:—The friction (1), (Figs. 15 and 16, p. 40), is keyed fast on the tin roller shaft (2). Loose on the same shaft is the friction cone (3), covered as usual with leather, and capable of being slid along the shaft. Cast to the friction cone (3), is the pinion (4), gearing into the carrier wheel (5). The pinion (4) has a flange (6) cast to it; its teeth are also wider than the teeth of the carrier wheel (5), to allow of the friction cone (3) being disengaged from the fast friction cone (1). On the rim of the carrier wheel is cast an inclined piece (7), capable of acting on the flange (6) of the pinion (4). This pinion has also a groove cut into its boss, into which a fork of a lever (8) fits, weighted with a counter weight (8). This weighted lever always tends to slide the cone (3) into contact with the cone (1), and so couple them together. Now it will be obvious that the lifting motion should be brought into action immediately the faller has been unlocked. If put into action too soon, one motion would be acting against the other, and a breakdown would be the result; and if too late it would be useless. To insure both motions working in harmony, the unlocking of the faller is made to liberate the weighted lever (8), and thus allow it to put the friction cones into gear. This is accomplished by means of the connecting rod (9), which forms a lock for the end of the connecting rod (10), which latter is coupled to the weighted lever (8). The two rods work at right angles to each other; on the unlocking of the faller, the connecting rod (9) is pulled in the direction of the arrow until it releases the stud on the rod (10), and so liberates the rod (10) and the weighted lever (8). As soon as the friction cones are in gear, the faller commences to be lifted, motion being communicated at the proper ratio by the volute wheels (11) and (12). By the time the faller is clear of the yarn and its work done, the incline (7) on the carrier wheel will have come in contact with the flange (6) on the pinion (4), and forcing it endwise by its wedge-like action, will cause the frictions to be drawn asunder, and thus arrest the motion from the tin roller to the faller. This action is a very beautiful one.

Self-stopping couplings to the cam shaft are common, but these stop during less than a revolution of the apparatus. For the above purpose the stopping must be effected anywhere between a part of a revolution and three revolutions or more: no two draws are alike, since, as the cop is built up, less and less of the spindle is left bare, and therefore the faller is lifted less, and the apparatus must be disengaged earlier. By setting the incline so that the disengagement takes place immediately the faller has left the yarn, it is always safe; the arc of motion of the faller being comparatively small, say about 80 degrees when beginning on the bare spindle, and gradually becoming less until it is only about 30 degrees.

When the mule is backing off, the faller reverses the train of gearing, and removes the incline (7) from contact with the flange (6) of the pinion. This action would allow the cones to go into gear again, if not prevented by a stop (13), which acts on the weighted lever (8). The carriage, when near the termination of its outward run, brings a part of the weighted lever (8) over against the stop. The greater the arc of motion of the faller during the backing off, the greater the motion of the carrier wheel (5), the further the incline (7) is removed from the flange (6), and the more revolutions the pinion (4) makes. Whether the faller moves through a large or small arc, it is always liberated from the control of the tin roller at the proper time. The whole operation occupies only about one second. It is the short time allowed which forms one of the difficulties of this difficult problem.

The stop (13) which keeps the friction cones (1)

and (3) out of gear during the backing off, keeps them so until the lock of the faller sliding the connecting rod (9) forward, locks the connecting rod (10), as explained before.

Another important feature of this operation is the speed at which the parts are allowed to work. The speed of the spindles, at the termination of the inward run, is too quick to overcome this difficulty, an extra driving belt is used for driving the "self-acting" pulley; this belt has generally about half the speed of the main rim-shaft belt, both belts working on the same diameter of pulley, Figs. 17 and 18, page 40. The fast pulley is shown at (1), the loose pulley at (2), another fast pulley at (3), and the taking-in pulley at (4), also loose on the rim

Fig. 12.

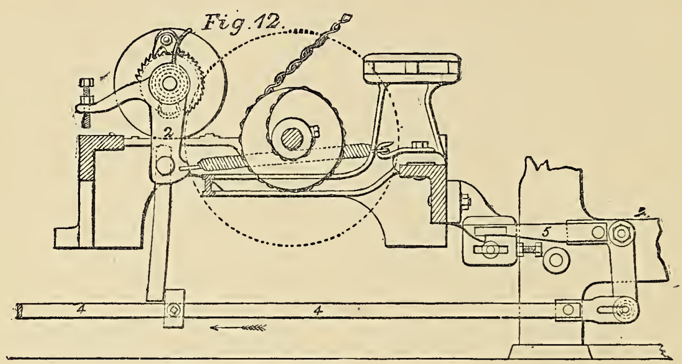


Fig. 13.

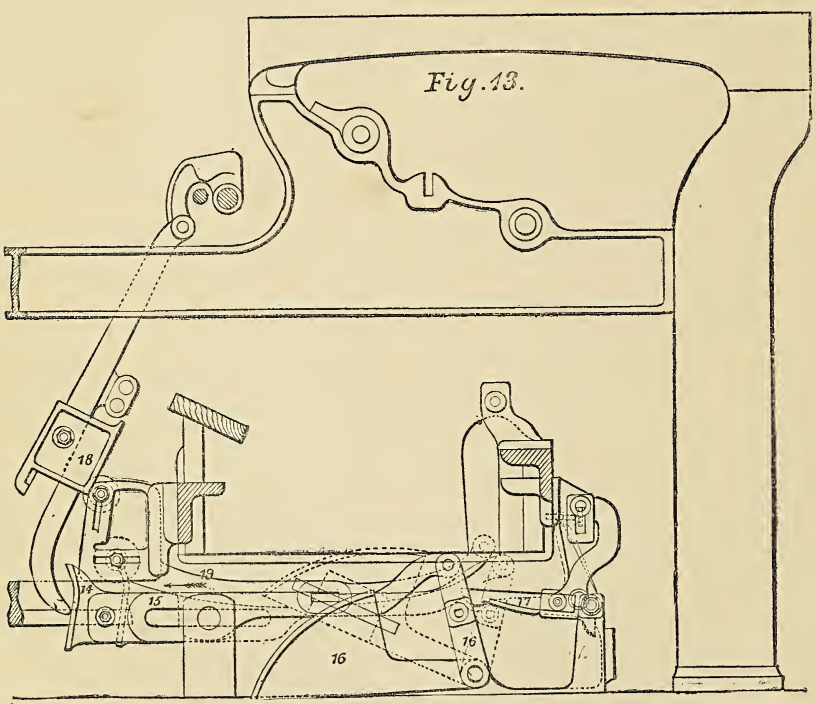


Fig. 28.—Improvements in Cotton-spinning.

allow of the use of the positive apparatus described, as it is found impossible to engage the parts sufficiently quickly. This difficulty is further increased by the spindles being put up to the spinning speed as soon as the carriage finishes its inward run; for it is impossible to rely on the momentum of the spindles for this purpose, the results being too variable. To shaft; both belts receive their motion from the counter shaft as usual (Fig. 18, p. 40). The cam shaft has three changes in this mule. When the carriage is making its outward run the quick belt is on the fast pulley (1), and the taking-in belt is on its loose pulley (4). At the proper time the cam shaft makes its first change, the rollers are stopped, and when the proper amount

of "twist" has been put into the yarn, the twist motion disengages the catch which holds the quick belt on the fast pulley (1), and allows a spring to move it on to the loose pulley (2). This allows the backing-off to take place in the usual way; after which the carriage makes its inward run, and just before the termination causes the cam shaft to make a second change, causes the slow belt to run on its fast pulley (3), and turns the rim at a comparatively slow rate. In fact, this belt acts as a kind of brake on the momentum of the rim shaft, which can be relied upon to be the same in every stretch. It is whilst this slow speed has the control of the mule that the lifting apparatus does its work.

When the faller has nearly lifted clear of the

An apparatus is also used by which the winding faller, during the time it is being "lifted," is enabled to govern the counter faller in such a manner that the counter faller is free to take up the slack yarn, if any, made during the rise of the winding faller, and is "depressed" below the yarn as usual before the spinning commences again.

"Double speed" motions are still used for the finest counts; but as this element would render the previous explanation more complex, it has been purposely omitted.

Ring Spinning.—In conclusion, it is necessary to allude to the question of ring spinning. Of late years considerable attention has been given to this subject, and many machines have been

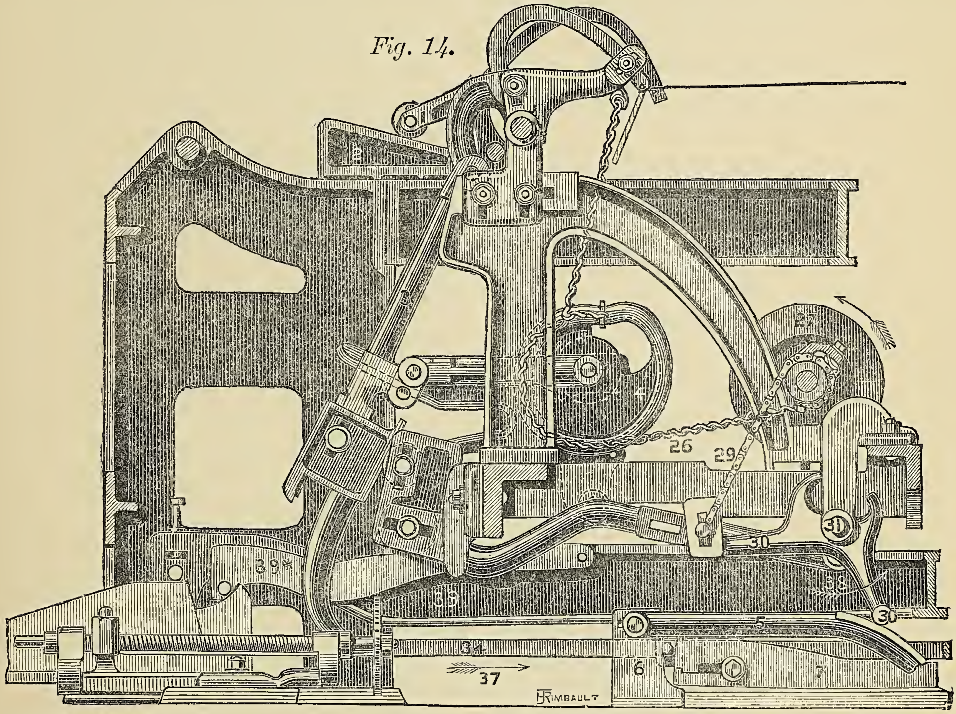


Fig. 29.—Improvements in Cotton-spinning.

yarn, a finger on it comes in contact with the cam shaft escapement, and allows the cam shaft to make a third change, which forces the slow belt off the fast pulley (3), and then forces the quick belt on the other fast pulley (1), when the spinning goes on at the proper speed. So quickly is the whole operation performed that it is impossible to see the change in speed from the slow to the quick belt, though of course it is easy to see the movement of the belts. The slower the operation the more perfectly it is done; but it is found to be well done with spindles running at 1,500 revolutions per minute.

During the outward run of the carriage the various parts are replaced in their proper position for effecting these operations.

set to work in this and other countries. In America it has long been in use. The best type of spindle in these machines is the outcome of American experience, the most popular being the "Rabbeth" and "Booth Sawyer."

Ring spinning has hitherto generally been substituted for fly throstle spinning, to which it is more closely allied; but in some cases it is competing with mule spinning, although, on account of its winding on wool bobbins, this is to a very limited extent. It is only suitable for medium counts, and requires good cotton to give the best results. It produces a stronger yarn than the mule, but not so strong as the throstle; nor is it so universal in its application as the latter. Further experience is necessary before it will be safe to say what is the proper position

of the ring spinning throstle in the economy of the cotton trade. At present opinions vary very much indeed on the question, and as to durability there are no data from which comparisons can be made with other competing machines.

We have thus traced the progress of cotton from its pod to the spinning-frame. Before entering on the subsequent processes it may be best to deal similarly with other fibres, such as the flax fibre, wool, and silk, and subsequently treat together all the various yarns in respect to weaving, dyeing, etc.

Commencing with a vegetable fibre, of which the chief member is flax, but which includes an enormous variety already described in the tables given at pages 6 and 7, *ante*, it may be noticed that flax is the only member of this family that is produced in the British Islands. Its mode of growth and preparation for the spinner has been fully described at the conclusion of the article "Agriculture," in the first volume of this work.

Before, however, tracing the flax to the factories where it is spun into thread, it may be well to remark that our manufacturers cannot depend upon home culture for a supply. There are only a few parts of England and Ireland where it is cultivated, and the quality of flax thus produced is not equal to that of Flanders. The linen trade being carried on rather extensively in the north of Ireland, it was thought that a national good might be wrought by teaching the Irish farmers to carry on this branch of agriculture properly; and accordingly a society was formed for this purpose at Belfast in 1841. In a report, describing the state of things in the country districts of Ireland at that time, it is said:—"In the most fertile districts of the country the culture of flax is totally unknown; in others the crop is neglected; in some given up from partial failures; and even where regularly brought into rotation, its management is so little comprehended, as to yield little satisfaction to the consumer, and scarce half of those profits to the growers that it might do. The source of failures and reasons for non-accomplishment of this have now been clearly understood by intelligent parties to be attributable solely to carelessness, such as not properly preparing the ground, weeding, steeping, grassing, and swinging or clearing the flax; and these being all faults referable to the farmer himself, he willingly finds excuses, blaming seasons, water, or anything but his own ignorance or indolence, and rests perfectly satisfied that a crop of flax cannot be rendered as profitable here as on the Continent." As a means of imparting instruction to the Irish flax growers, the newly formed society engaged two experienced Flemings to come over to Ireland and reside there some months, superintending the operations. Each year since then a report has been made of the proceedings; and great good has resulted from them, the growth of flax having materially increased. About the same time the culture of flax was undertaken in England, but it has not been attended with much success.

Of recent years a considerable amount of flax has been cultivated in Ireland. In the year 1880, according to the official return of agricultural statistics, there was an increased growth of flax over that of 1879 to the extent of 1,052,118 stones of 14 lbs. each, which amounted to about two stones increase per statute acre. It is also stated in the same report that the number of mills for scutching flax in Ireland in 1880 was 1,182, being a decrease of 12 compared with 1879, and of 317 in the 10 years, 1871-80; 1,140 of these mills in 1880 were in Ulster, 18 in Munster, 16 in Connaught, and 8 in Leinster. There were 504 mills with from 1 to 4 stocks, 337 having 5 or 6, 293 with from 7 to 12, 40 having from 13 to 18, and 8 having above 18 stocks; 976 were worked by water power, 140 by steam, 62 by water and steam, 2 by horses, and 2 were moved by the wind.

The flax-plants, after being so broken and beaten as to separate nearly all the central woody portion from the external fibres, are sent to market to be purchased by the flax-spinners. The fibres are wrapped up into the form of small bundles or "heads," measuring about two feet in length, and weighing two or three pounds each. The large buildings called "flax-factories," of which the most important are in or near the three towns of Leeds, Dundee, and Aberdeen, have a variety of machines for working up these fibres into the form of thread or yarn, by means of processes bearing more or less resemblance to those of the cotton-manufactories.

In the first place, as already explained, the heads of flax, when opened, are "scutched" at the ends, that is, they are fixed to a machine at one end, while the other end is rudely combed out. As the flax is in a much more dirty or dusty state than cotton, or wool, or silk, owing to the fragments of wood still adhering to it, all the early processes of flax preparation are extremely dusty, and it requires skilful arrangements on the part of the manufacturer to keep the work-rooms in a fit state for the operatives. When the ends of the flax are scutched, the fibres are cut into three pieces by means of a cutting machine, and the three lengths of each fibre are set aside for different purposes, the middle one being the best of the three.

Then ensues the process of "heckling" the flax, intended to separate, straighten, and cleanse the fibres. This is done in two ways; either by "hand-heckles" or by "heckling-machines." The hand-heckle is a square piece of wood covered with iron teeth about four inches long; the fineness of the teeth, and the distance at which they are arranged apart, being chosen with reference to the quality of the flax. The heckler grasps a handful of the flax by the middle, and draws first one side or end, and then the other, through the teeth of the heckle, until all the little fragments of dirt and bark are removed, and the fibres become ranged, smooth, and parallel.

But the heckling-machines (Fig. 30) effect this in a more expeditious manner. Several such machines are placed in a row, and every handful of flax passes through all the machines in succession. Each machine has a cylinder, on the

surface of which are a number of clasps or frames for holding the flax. The clasps are taken from the cylinders and placed on a bench, where boys are employed in fixing the flax into them by one end, leaving the fibres floating freely at the other. Girls are then employed to place the clasps on the surface of the cylinder, ranging them one by one round it. The cylinder being set in motion, the loose flax fibres are compelled to pass among and between a number of teeth fixed at a particular part of the machine, by which they become combed or heckled to a certain extent. The machine is then stopped, and the clasps with their flax are removed and placed upon a second machine containing teeth a little finer than those of the first machine. A second heckling is given to the fibres; after which they are removed to a third, a fourth, a fifth, and a sixth, each one having heckle-teeth finer than those of the one preceding it. When half the length of each group of fibres has been thus heckled, the flax is taken out of the clasps, and re-clasped at the other end, the end being now left free and flowing which had before been confined in the clasps. This end then undergoes the six consecutive hecklings as the other had done.

By this rather complicated process the flax has become very soft, silky, glossy, and free from every kind of dirt. As the fibres of flax are very different in quality among themselves, they are carefully sorted before undergoing any further preparation: every minute shade of difference in colour, fineness, and smoothness being attended to in this sorting or classification.

Next commence the processes more nearly belonging to the spinning of the flax. The individual fibres, still only a few inches long, have to be combined together in a continuous thread before they can be spun into yarn. To effect this the flax is laid on a smooth table or platform connected with the "drawing-machines" (Fig. 31), and is from thence drawn between small rollers, by which the fibres are combined into a continuous "sliver" or riband. The ribands so formed fall into cylindrical cans placed upright at one side of the machine. Each of these ribands is about an inch and a half in width, and presents a silvery and rather delicate appearance. To reduce it to the state of yarn or thread, the riband undergoes a long series of "doublings," "cardings," and "drawings." Several cans containing the ribands are placed together (Fig. 32), and the ribands are so drawn between rollers as to form one riband, thinner and narrower than the original ones, but very much longer; then these narrower ribands are carded and drawn, then doubled again, then carded and drawn, and so on several times, until at length the resulting product is a beautifully smooth band or narrow fillet of flax.

The workers in flax draw a distinction between "line" and "tow." As soon as the flax has passed through the heckling-machines it ceases to be called by its original name; the good portion is called "line," and the inferior "tow." The heckling-machines not only comb out the dirt and fragments, and range the fibres parallel, but they also remove the short and defective fibres, which remain adhering to the heckle-teeth. The short fibres so detached from the rest are, by a peculiar adaptation of the heckling-machine, removed from it in a state of a continuous sliver of *tow*, and this sliver, by being drawn, doubled, &c., is prepared for spinning in the same way as the "line," or better portion of flax. In some cases the loose tow, instead of being made into a continuous riband at the heckling-machine, is carded into that form by a separate piece of apparatus (Fig. 33).

Next comes the "roving," by which the "drawings" of flax are brought to the state of a loose, small, soft cord. This is done in the same manner as for cotton-roving. The spinning, however, so far differs from that of cotton, that the material is wetted before being spun. Flax-spinning is conducted on the "bobbin-and-fly" principle, and not on the "mule" principle. Besides the apparatus proper for spinning, there must be arrangements for wetting the thread. The object of this wetting is to produce a finer and smoother yarn than could result if the flax were dry; and one of the improvements of recent years has been to use warm water instead of cold, since it is found that the same flax, prepared in the same way, can be spun to a greater degree of fineness when wetted with warm water than with cold.

The arrangement of some portions of the spinning-mechanism is seen in section in Fig. 34, where water is seen to be flowing down upon the rollers through which the flax passes in the act of being spun. As the spindles or flyers revolve some thousands of times in a minute, there is a continual spray of water being thrown off by the yarn; and the spinners, to protect themselves from its effects, wear thick aprons. In the modern machines, where warm water is employed instead of cold, the water is contained in a trough attached to the machine, and is heated by steam admitted through a small pipe.

By such means the flax is brought into the form of yarn, and according as this yarn is to be employed for weaving into linen, or for sewing-thread, or for lace-thread, so is it treated after leaving the spinning-machines. If for weaving, it is reeled into hanks on a winding-machine, and then made up into bundles. If for sewing or for lace-work, two or more yarn-threads are doubled together, and spun or twisted into a thread of greater thickness and strength.

The yarn spun in flax factories is woven into several kinds of goods, of which linen is the principal. The weaving is carried on principally in three different districts: in the West Riding of Yorkshire, in Scotland, and in the North of Ireland. In Yorkshire the goods are woven chiefly by the hand-loom, and consist of *linen, duck, check, drabbet, tick, huckaback, diaper, drill,* and *towelling.* In Scotland, where power-looms have been extensively introduced, flax is woven into *shirting, damask,* and *table-linen* at Dunfermline; and into *sheeting, bagging, sacking, dowlas, sail-cloth, canvas* for floor-cloth, and other coarse goods, at Dundee.

Passing over the manufacture of hemp of

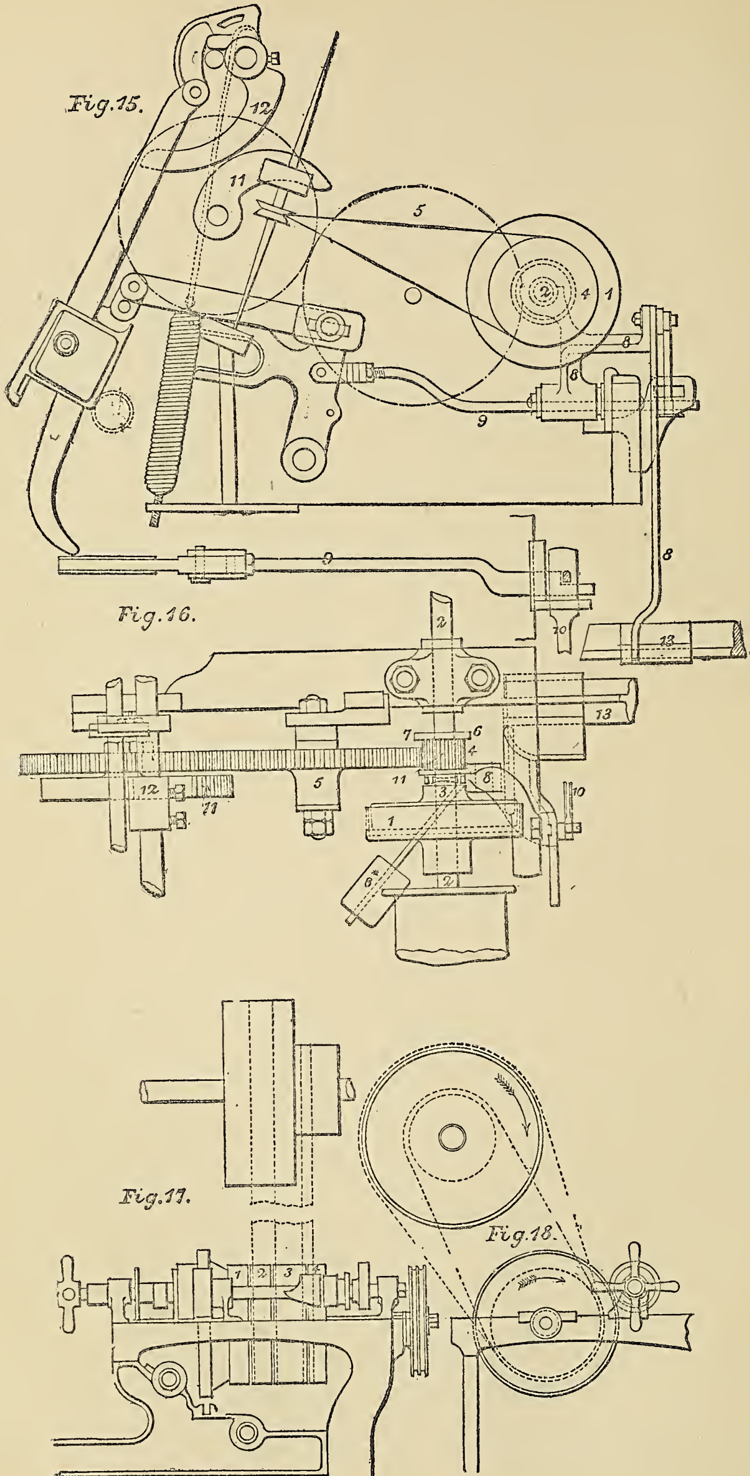


Fig. 29.—Improvements in Cotton-spinning.

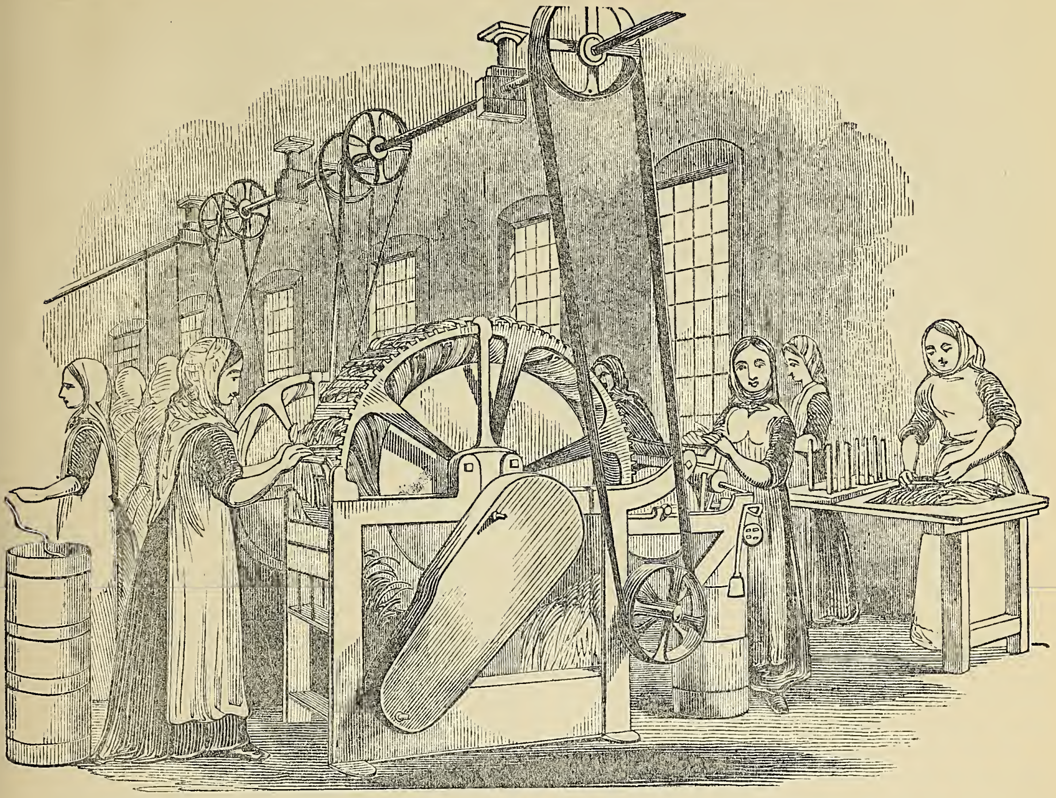


Fig. 30.—Flax-heckling.

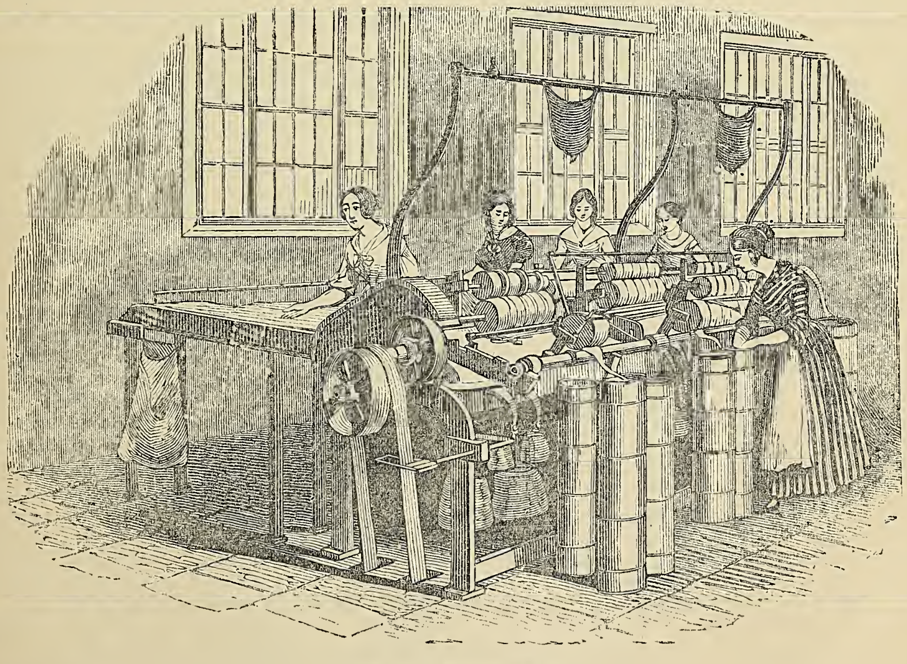


Fig. 31.—Flax-drawing.

various kinds, we next turn to one that has of late years risen to great importance, namely, that of *Jute*.

We are indebted for the following account of the manufacture of jute to a paper read by Mr. William Fleming, of Barrow-in-Furness, at the meeting of the Institution of Mechanical Engineers, held at Barrow in July, 1880, and have also to state that the text has been copied from a reprint published in *Engineering* on August 6, 1880. Mr. Fleming remarked as follows :—

While jute has long been known to the natives of Bengal, and largely used by them in various textile manufactures, and for paper-making purposes, its introduction into this country is of comparatively recent date.

In 1796 the East India Company imported some small quantities of jute, and afterwards continued importing it in small lots now and then ; but it made no progress whatever with the manufacturers of this country. What was thus imported seems to have been employed in the neighbourhood of London, in the production of door-mats, ropes, etc. Portions of the samples, however, appear to have found their way to Abingdon, in Oxfordshire, where there were a few manufacturers of sackings and woollen carpetings. There it was spun, by hand, and used up to a small extent in some of their fabrics. The Abingdon manufacturers therefore appear to have the credit of being the first to employ jute in textile fabrics in this country.

About 1833 some of the jute yarn thus spun at Abingdon was sent to Dundee, where the matter attracted attention ; and shortly afterwards was commenced at Dundee that manufacture of jute, which has resulted in such an extraordinary development of this industry in Great Britain, Ireland, and the Continent. The increase in the consumption of jute during the last fifty years is most remarkable. The total export of jute from Calcutta in 1829-30 amounted to 20 tons, valued at £60; it has now risen (in addition to the enormous consumption for manufacturing purposes in Bengal itself) to upwards of 350,000 tons, or nearly 2,000,000 bales annually, amounting in value to about £6,000,000.

Jute is mainly grown in Bengal, and exported from Calcutta. It is sown in March and April, and during the following three months attains a height of from ten feet to twelve feet, while the stems reach from one inch to two inches in circumference. In 1881 accounts reached this country to the effect that the growth of jute had been commenced in Egypt, and in the southern portion of the United States of America.

Shortly after the plant has flowered it is cut down near to the ground, tied up in bundles of from 50 to 100 plants each, and "petted," that is, steeped in stagnant water from eight to ten days, till the "bast" (or the fibre lying between the bark and the stem) can be separated from the wood. It is then removed from the water and beaten gently against a board, until, with a little management, the native operator can strip off the whole from the stem without damage to either stem or fibre. The fibre is then drawn through the water until all impurities are washed or picked off. It is then dried in the sun, and, after having been assorted into different grades of quality, is exported, under various distinctive marks, in bales of 400 lbs. each, to London, Liverpool, Dundee, Barrow, and other markets.

Softening.—The jute fibre being of a somewhat harsh nature, the first process which it has to undergo after being released from the bale, where it is very tightly compressed, is that of softening. This is done by dividing the jute into stricks or handfuls, and passing these stricks through between a series of heavy fluted rollers, which, by crimping and crushing, and in a manner rubbing the fibres, render them softer and more yielding.

The softening machine consists of four horizontal rows of fluted rollers about 9 inches in diameter and 2 feet 6 inches long, and ten rollers in each row. Each roller in the bottom or fourth row bears the weight of the three rollers above it, those in the third row are pressed by the weight of two rollers, and those in the second row by the weight of one roller. The stricks of jute pass first between the pairs of rollers constituting the first and second rows, then return between the second and third rows, and pass lastly between the third and fourth rows, being delivered in a softened condition at the opposite end of the machine to that where they were introduced, and having been subjected during the process to an increasing weight as they entered between the different rows. The softening of the jute is at the same time assisted by an operation called "batching," *i.e.*, the sprinkling of the stricks with oil and water whilst they are passing through the machine. This is done by having two cisterns, one containing water and the other containing oil, placed over the machine. Inside the cisterns are revolving rollers which lift the liquids, and discharge them over a scraper, or doctor, dropping them upon the jute as it passes between the rollers.

Breaker Card.—The jute having been softened, and weighed into bundles, is conveyed to the breaker card.

The principal parts of this machine consist of a cylinder 4 feet in diameter by 6 feet wide on its working surface, covered with sharp steel pins inclined slightly forwards in the direction in which the cylinder revolves; and of a number of small rollers arranged round the periphery of the cylinder, each of these rollers being also covered with pointed pins. The stricks of jute are laid or spread by the attendant upon an endless travelling sheet, which conveys them to the first roller, called the feeder; and the pins which cover the surface of this roller enter the jute, and carry it forward to the point where it comes in contact with the pins of the cylinder. The surface speed of the pins of the feeder being about 10 feet per minute, whilst the speed of the pins of the cylinder is about 2,000 feet per minute, the fibres which are slowly presented and delivered by the feeder receive a severe combing or dressing from the pins on the cylinder before they are finally released by the feeder. The cast iron shell which encases the

feeder for about one-sixth of its circumference serves to keep the fibres embedded in the feeder pins, so as to prevent their being carried off by the cylinder before being properly carded. A large quantity of the fibre, however, when struck by the pins of the rapidly revolving cylinder, is broken off and carried forward on the points of the cylinder pins; and it is to straighten out, comb, and split these portions that the other rollers, called workers and strippers, are applied.

The first roller that acts, after the fibres have left the feed roller, is the worker. This roller, which is about 9 inches in diameter, is placed with its pin points at a distance of from $\frac{1}{16}$ inch to $\frac{1}{8}$ inch from the points of the cylinder pins. The angle of the worker pins is very much more acute than that of the cylinder pins, and inclined in the opposite direction. The roller revolves in the same direction as the cylinder, but at a speed of only about 50 feet per minute. The effect is that the fibres projecting from the pins of the cylinder are caught on the pins of the slowly revolving worker; and as the direction and pull of the cylinder pins tend to force the fibres on to the pins of the worker, a considerable portion is retained by the latter. The worker is in its turn cleared of fibre by the stripper, a roller about 13 inches in diameter, which revolves at a speed of about 430 feet per minute in the opposite direction to the worker; and, travelling with pins inclined forwards, it strips the fibres from the worker, and is afterwards itself cleared by the still more rapidly travelling cylinder.

The same process is repeated at the second worker and stripper, which are placed rather closer to the pins of the cylinder than the first two rollers. After passing the second worker and stripper, the fibres are carried forward to the doffer, a roller about 16 inches in diameter, which travels in the same direction, and at about the same speed as the worker, and has its covering similarly arranged, except that in the doffer the pins are rather finer and more numerous. The pins of this roller are set close to those of the cylinder, so that the whole of the fibres are caught by them, and carried round to the two doffing rollers, which take the jute from the doffer in the form of a continuous broad sheet or fleece. This thin sheet of carded jute, after it issues from the doffing roller, is gathered together or contracted from about 5 feet to 4 inches by means of a tin conductor; and it then passes through the delivery rollers in the form of a continuous sliver, and falls into a can (see page 18, *ante*, in respect to cotton carding).

The surface speed of the doffing and delivery rollers is generally about fourteen times quicker than that of the feed roller; consequently if the jute be spread so that the feed roller receives about two pounds per yard, the sliver delivered into the can will measure about seven yards per pound.

The tin rollers under the workers and strippers are to prevent the fibres, as much as possible, from falling to the ground, when the stripper is clearing the worker.

Finisher Card.—The jute sliver as delivered by the breaker card is not considered to be sufficiently carded for most purposes; and it is therefore necessary that the process of carding should be repeated on a second machine called the finisher card. The principle on which this machine works is exactly the same as that of the breaker card; but instead of only two workers and two strippers, there are sometimes three, four, or five pairs of these rollers, and the pins on the surface of the cylinder and rollers are finer, and set closer to one another, so as to comb and split the fibres more efficiently. The finisher card is fed by slivers from twelve cans from the breaker card upon an endless travelling sheet, similar to that used in the breaker card; which carries them forward to be acted upon by the cylinder of the finisher in the same manner as the stricks of jute are acted upon in the breaker card. It will be understood that the slivers, as delivered by the breaker card, although continuous, must necessarily be rather irregular, *i.e.*, thicker in some parts than others; but by putting twelve of these already partially carded slivers through the finisher together, a kind of average is struck, and the slivers delivered by the finisher card are much more regular and even. The "draft," or proportion of speed between the delivery roller and feeder of the finisher card, is about 16 to 1; so that, being fed by twelve slivers, each measuring about 7 yards per pound, and these being subjected to draft of 16, the sliver delivered by the finisher card will measure about $9\frac{1}{3}$ yards per pound.

Drawing Frame.—The next process after carding is to have the fibres of jute drawn out straight, and laid parallel alongside one another; and this is accomplished on a machine called the drawing frame.

There are several kinds of drawing frame, all intended to produce the same results; but the kind most in use is the system called the "spiral gill drawing-frame." In this machine the slivers, which have been delivered into the cans from the finisher card, pass over a conductor plate and thence between three rollers, which are called the retaining rollers, and are, in fact, the feed rollers of the machine. Just in front of the delivery side of these rollers is a series of travelling bars, on which are fixed hackles or gills, *i.e.*, brass stocks with steel pins standing upright in them. These bars, with the gills attached, travel forward from the retaining rollers, carrying with them the jute fibres into which the pins penetrate, their speed being the same as that of the retaining rollers, or just as much faster as will insure that the slivers are kept tight and do not rise off the pins. The bars are propelled by means of two longitudinal screws, one at each end of the bar, cut at a pitch varying from $1\frac{1}{2}$ to 2 threads per inch. The end of the bar which enters into the thread of the screw is bevelled to the angle of the thread, so that the body of the bar and the pins are quite vertical, whilst the end fits the spiral; and there being one bar in each thread of the screw, when the screws revolve the bars glide forward, supported on steel slides. These screws are called the top screws, and the length of their threaded

part is made suitable for the length of fibre; say about 10 inches or 11 inches for carded jute. As each bar arrives at the front or further end of the top screws, it drops from the slide which has been supporting it in position, into the threads of two bottom screws placed exactly under the top screws, cut to the same hand, but revolving in a contrary direction. These bottom screws accordingly carry back the bar, supported on bottom slides, and with its pins still upright, to the other end of the frame, where the thread of each screw is terminated by a projecting cam, by which the bar is lifted up again into the top screw again, close to the retaining roller, causing the pins of the gills to penetrate the sliver which the retaining roller is delivering. Thus a continuous forward travel of bars is maintained for 10 inches or 11 inches in length in front of the retaining rollers, moving at what is practically the same speed.

Fig. 32.—Flax-doubling.

At the front or delivering end of the screws where the bar drops out of the sliver, are the drawing roller and the pressing roller above it, the former being made of steel, about $2\frac{1}{2}$ inches in diameter, and the latter generally of cast-iron, covered with leather, about 8 inches in diameter. These rollers, which are pressed together by means of weighted levers, move at a speed about six or seven times greater than the retaining rollers or gills; consequently the fibres, when delivered by the gills as the travelling bars drop from the top to the bottom screws, are seized between the rollers and drawn away from the pins of the gills, which act as a kind of comb, holding them back and insuring that they do not enter the bite of the rollers in a crossed or tangled state.

The length of each travelling bar is about 3 feet, and there are fixed on it four gills, each 6 inches wide on the pins. Each set of bars and gills, with its retaining and drawing rollers, conductors, etc., constitutes what is called a carriage; and drawing frames are made with one, two, three, four, or five carriages. Thus a drawing frame of two carriages, and four gills per carriage, will have eight sets of gills; and as two slivers from the finisher card are supplied to each gill, the number of cans at the back of the machine will be sixteen. Assuming the speed of the drawing roller to be six times that of the retaining or feeding rollers and gills, it is evident that the sliver delivered by the drawing roller will be six times longer than when it enters the machine; and as there are two card slivers to each gill, and each card sliver may be assumed to measure $9\frac{1}{3}$ yards per pound, the

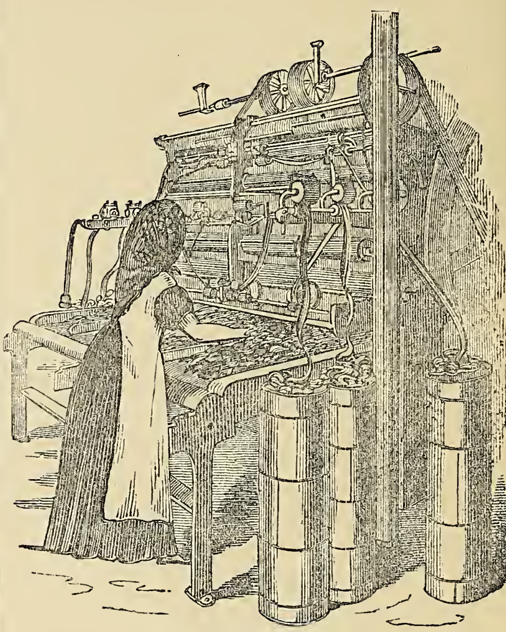


Fig. 33.—Tow-carding.

sliver coming from between the drawing and pressing rollers will measure about 28 yards per pound. But, for the purpose of completing the process of straightening the fibres and laying them parallel, as well as more effectually equalising the slivers, it is necessary to put the jute through a second drawing frame; and, therefore, it is more convenient to unite the slivers from two gills upon a doubling plate arranged for the purpose in front of the drawing roller, and so to deliver the sliver from all the eight gills comprised in the two carriages through four pairs of rollers, called delivery rollers, into four cans; the sliver in each can will consequently measure about 14 yards per pound.

The second drawing frame is constructed in an exactly similar manner to the first drawing frame, except that the pins in the gills are rather finer and ranged closer together; and instead of the slivers from two gills being united together in front of the drawing roller, the

slivers from each gill are carried straight from the drawing to the delivery rollers and run into the can, thus making eight deliveries from the machine. As there are two slivers, each of 14 yards per pound, put up to each gill, the sliver as delivered into the can from this second drawing frame, if the draft on the machine is six, will measure 42 yards per pound.

Roving Frame.—The next machine in the system of preparing machinery is the roving frame. The object of this machine is to draw out still further the fibres in the jute sliver, and wind them on bobbins in a form convenient for the final process of spinning into yarn. The manner of drawing out the slivers is exactly the same as that employed in the drawing frames; but as only one sliver is put up to each gill in

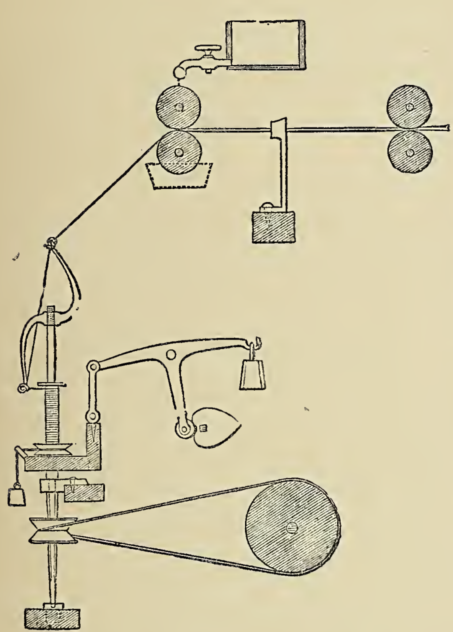


Fig. 34.—Wet-flax Spinning.

the roving frame, and that sliver measures about 42 yards per pound, narrower and smaller gills serve the purpose, and eight gills can be fixed on each bar instead of four; and in consequence of the slivers being so much lighter, the pins of the gills are finer and set closer together. The draft of the roving frame is usually about seven, so that the sliver delivered by the drawing roller of the roving frames will measure about 294 yards per pound.

This is too thin a sliver to deliver into a can; and for that reason, and also for general convenience, the sliver is twisted slightly and wound on to a bobbin; in this form it is called "rove." In order to twist the sliver into rove and wind it on to the bobbin, there are employed a spindle and flyer, constructed on the same principle as in similar machines for cotton and other fibres; but for jute the parts are larger and stronger. The number of spindles in a jute roving frame may vary from twenty-four to sixty-four; a very usual number to put in is fifty-six, and as there must be a gill for each spindle and flyer, seven carriages with eight gills on each bar are necessary to supply fifty-six spindles. The spindles with their flyers stand vertically in two rows in front of the drawing rollers, and revolve at a speed of about 600 revolutions per minute. Inside the flyer, and turning freely on the spindle, is placed the bobbin which is to receive the rove. This bobbin is driven by gearing independently of the spindle and flyer, but revolves in the same direction. The amount of twist given to the rove should be only just sufficient to give it strength to unwind from the bobbin, in the subsequent process, without allowing the fibres to separate. Now, suppose the suitable twist for rove to be one turn per inch of sliver delivered; then the speed of the drawing roller must be arranged so as to deliver one inch for each revolution of the flyer; and the speed of the bobbin must be calculated to be just sufficiently behind that of the flyer to take up the quantity delivered by the drawing rollers. For instance, the spindle and flyer make 600 revolutions per minute, the roller delivers 600 inches per minute, and the circumference of the bobbin shank is 5 inches; the speed of the bobbin will have to be 480 revolutions per minute, or 120 less than the flyer, because by lagging behind to that extent the bobbin will wind up 120 laps, each 5 inches long, or 600 inches, per minute. But, as the bobbin fills, the diameter on which it winds continually increases, and the speed must be diminished accordingly. Thus, when the bobbin is nearly full, its circumference will be 15 inches, or three times what it was at starting; consequently the bobbin will have to run only 40 revolutions per minute behind the flyer, in order to wind the rove with one twist per inch. In order to wind the rove regularly from top to bottom of the bobbins, the rail on which these are carried is made to rise and fall, so that the bobbin moves up and down inside the legs of the flyer; and the diminution in speed of the bobbin is caused by a projection attached to the lifting rail being arranged to release a catch each time that the rail arrives at top and bottom of its traverse. The regulating motion is obtained from a bowl or pulley with a leather face, which is made to revolve by contact between two flat circular iron discs rotating in contrary directions. Each time that a catch is released, either at top or bottom of traverse, the bowl is allowed to slide a little nearer to the centre of the two discs, whereby its speed is diminished; and thus the speed of the bobbin is also reduced for each successive lap.

As already explained, the jute fibres in this slightly twisted form are termed "rove." But for the heavier classes of yarn (say when 1lb. measures less than 400 yards), it is very usual to make the "yarn" on the roving frame. To do this it is only necessary to increase the twist sufficiently to give proper strength to the yarn.

Spinning Frame.—The object of this machine, which completes the first stage in jute manufacturing, is to reduce the rove which comes from the previous machine to the required size, and then to twist the fibres together so as to form what is known as "yarn."

The number of spindles in a spinning frame varies according to circumstances; but for an average class of jute yarns, a very usual number is sixty-four on a side, arranged in one row, at a pitch or distance from one another of $3\frac{3}{4}$ inches. The main parts of the machine are: the rack or creel for the bobbins containing the rove, the retaining rollers, the binding plate, conductor, drawing rollers, thread plate, spindle and flyer, and bobbins to receive the yarn. The bobbins containing the rove are placed on pins fixed on the rack, and the rove is introduced through a conducting plate between two fluted rollers pressed together, which form the retaining rollers; then over the binding plate and through a narrow conductor into the bite of the drawing roller and pressing roller, the former being made of iron, and the latter of wood and pressed against the drawing roller by means of steel springs. The drawing and pressing rollers run at a surface speed considerably in excess of the retaining rollers, the difference being regulated by change wheels to suit the size of yarn required. We will assume the drawing roller to be moving seven times faster than the retaining roller, so as to give a draft of seven. The slight twist which the rove has received in the roving frame gives it sufficient consistency to hold together and pull the bobbin round on its pin, so as to supply the retaining rollers; but when gripped at one end between the retaining roller and its pressing roller, and at the other end between the drawing and pressing rollers, the latter pair moving at the quicker speed, the slight twist which the fibres have received does not prevent them from parting. Not being supported by gills as in the drawing and roving frames, the rove is made to press against the binding plate, in order to retain the twist, and so prevent the fibres from separating too easily and from passing through the drawing and pressing rollers in an irregular manner.

By the draft of seven, the rove is elongated from 294 yards per pound, as it enters the retaining rollers, to 2,058 yards per pound when it passes from the drawing roller. The fibres are twisted by the spindle and flyer in the same manner as in the roving frame; but the amount of twist given to the yarn is very much greater than that given to the rove, and the bobbin is not, as in the roving frame, driven by wheels, but is dragged round after the flyer by the thread, and is retarded by friction sufficiently to wind on the yarn, the friction being regulated by the attendant to suit the strength of the yarn.

In illustrating the action of these different machines, a certain weight of jute has been assumed to be laid on the feed sheet of the breaker card, with certain drafts and doublings in the separate subsequent machines; the result of which would be to produce yarn known as "7 lb.," because each "spindle," or length of 14,400 yards, would weigh 7 lbs., but by varying the weight, drafts, or doublings, other sizes of yarn are produced. The finest yarns in jute, made from the best qualities, are about $1\frac{3}{4}$ lb. to 2 lbs. per spindle, or say about $\frac{1}{4}$ lb. per mile; whilst from the coarsest class, yarn is made of which a mile will weigh more than 30 lbs.

The yarns, having been prepared in the necessary forms for the looms, are woven into fabrics of great variety, suitable for the requirements of every market in the world, and these fabrics undergo various processes of calendering, mangling, and finishing.

Jute is the cheapest fibre known, and hence the very general demand for jute fabrics in every country. Jute manufactures are now almost entirely used for the conveyance of grain, flour, rice, linseed, coffee, pepper, saltpetre, etc.; as also for guano and all chemical manures; while in the export of the raw materials, cotton and wool, nothing else is now employed for packing. All makers of textile goods now use jute hessians and baggings for the packing of their manufactures.

The finer qualities of jute yarns are woven into fabrics suitable for the production of certain cloths, tapestries, etc., for furniture purposes (such as the "Kalameit," now produced in the Barrow Flax and Jute Works), and for carpets, rugs, etc. They are also used largely, in combination with cotton, silk, and woollen yarns, in the weaving of numerous ornamental goods. In fact, the list of the varied purposes to which jute, jute yarns, and jute fabrics are now extensively applied is curious and remarkable, embracing, as it does, telegraph cables, wire ropes, oilcloth and linoleum manufactures, ropes, twines, cords, etc., even down to artificial hair.

The cuttings (or the few inches of hard fibre cut from the bottom of the plant in India) are now largely used by the paper makers in this country, as well as in India, America, and the Continent; and the wastes made in the general manufacture of jute, which cannot be spun over again, come into value in connection with paper making, felt making, and other purposes.

This enormous and general demand has brought about a more than equivalent producing power in this country, in India, and elsewhere; and during the past few years the jute trade has been suffering from the effects of this over-production; but as the requirements of the world are increasing so rapidly, the improved demand must soon rectify this unfortunate state of things.

Having thus traced the progress from growth to the conversion into yarn of cotton, flax, and jute, as vegetable fibres, we next turn to those of an animal nature, the two most important of which are silk and wool.

Silk.

It has been remarked that the four great classes of textile fibres employed for the production of clothing, viz., cotton, silk, wool, and flax, are essentially different in their origin.

They are all delicate filaments, but they present little in common as respects their formation. Cotton and flax are of vegetable growth, one proceeding from the seed-pod, and the other from the stem: wool and silk are of animal growth, one proceeding from the outer covering of the animal which produces it, and the other elaborated by a little insect from a glutinous substance within its body. That substances so dissimilar should all alike be brought within the power of the loom, and employed in the formation of beautiful cloth, is a fact strikingly illustrative of man's ingenuity, and seems to point to the probability that increased resources will be laid open to those who seek among the natural riches presented to our use.

The little silk-producing animal—first a worm, and then a moth—requires close and careful attention in order that the produce of its industry may be made available to man. It is to the Chinese that we owe the knowledge of this art; among whom it has been practised from very remote times. Long before the inhabitants of Europe knew that silk was produced from an insect at all, the manufacture of silken goods was common amongst the Chinese. The early Greek writers spoke of the lustrous beauty and brilliancy of the Asiatic robes; and in more than one passage alluded to China (or Seres, as it was then called) as the place whence they came. One of these writers, supposing that silk was a vegetable production, spoke of it thus:—

> "Nor flocks nor herds the distant Seres tend;
> But from the flowers that in the desert bloom,
> Tinctur'd with ev'ry varying hue, they cull
> The glossy down, and card it for the loom."

The introduction of silk-rearing into Europe was brought about in a somewhat romantic manner. According to the received version of the story, two Persian monks in the time of Justinian, having been employed as missionaries in some of the Christian churches, found their way eastward to Seres or China. They there viewed with curiosity the usual dress of the Chinese, the manufacture of silk, and the myriads of silk-worms. They soon discovered that it was impracticable to transplant the short-lived insect, but that in the eggs a numerous progeny might be preserved and multiplied in a distant climate. They observed the labours of the silk-worm, and strove to make themselves acquainted with all the manual arts employed in making up the material produced into so great a variety of fabrics. On their return to the West, instead of communicating the knowledge thus acquired to their own countrymen, they proceeded to Constantinople, the capital of Justinian's empire. They imparted to the emperor the secret, until then known only to the Chinese, that silk was produced by a species of worm; and acquainted him with their belief that the eggs of these might be successfully transported, and the insect reared in his dominions. They likewise explained to him the modes of preparing and manufacturing the slender filament, which had till then been a mystery in Europe. By a promise of a large reward, these men undertook to return to China, and there, by means of much precaution and with great difficulty, they succeeded in obtaining more silk-worms' eggs. These they concealed in a hollow cane; and at length, in the year 552, they conveyed them in safety to Constantinople. The eggs were hatched in the proper season by the warmth of manure, and the worms were fed with the leaves of the wild mulberry-tree. The worms in due time spun their silk; and the monks gave all the instruction in their power concerning the mode of manufacturing it into thread for the weavers.

This department of industry was for more than six hundred years confined (so far as Europe was concerned) to the Eastern or Byzantine empire. It was not till about the time of the Crusades that it spread westward or northward. In the twelfth century silk-rearing began to be practised in Sicily, in the thirteenth century in Italy, in the fourteenth in Spain and France, and in the fifteenth in England. But this latter point, the introduction of silk-rearing into England, is more a matter of curiosity than of commercial advantage. It is now known that various circumstances, including that of climate, prevent the rearing of silk-worms from being profitably carried on in this country; but this fact was not known three centuries ago. James the First was extremely solicitous to promote this branch of industry in England; and the cultivation of the mulberry-tree (a necessary part of the proceedings, as we shall presently explain) was commenced in St. James's Park. Evelyn in his "Diary," under the date 13th of June, 1649, says:—"Lady Gerrard treated us at Mulberry Garden, now the only place of refreshment about the town for persons of the best quality to be exceedingly cheated at: Cromwell and his partisans having shut up and seized on Spring Gardens, which till now had been the usual rendezvous for ladies and gallants at this season." In relation to this passage, an anonymous writer remarks that "The Mulberry Garden was planted by order of James I., who attempted in 1608 to produce silk in England, and to that end imported many hundred thousand mulberry-trees from France, some of which were planted under his own inspection, and the rest dispersed through all the counties with circular letters, directing the planting of the trees, and giving instructions for the breeding and feeding of silk-worms. In 1629 a grant was made to Walter, Lord Aston, etc., 'of the custody of the garden, mulberry-trees and silk-worms, near St. James's, in the county of Middlesex.' How soon after this the silk-worms disappeared, and the gardens were opened to the gay world in the manner indicated by the above quotation from Evelyn, does not appear. He does not speak of the opening of the Mulberry Gardens as anything new."

During the reign of George the First another attempt was made of a similar kind. A company was incorporated, and empowered to obtain a lease for one hundred and twenty-two years of Chelsea Park; mulberry-trees were extensively

planted, and large buildings erected for managing the rearing of silk-worms. But the enterprise failed; and all subsequent attempts (of which there have been many) to introduce silk-rearing into England, as into the United States, have been equally unsuccessful as commercial speculations; partly on account of climate, and partly owing to the higher rate of wages in these countries than in the South, the employment being such as can have very little aid from machinery. Even so late as 1835, a company was formed for this object in Ireland, but without success.

China, India, Italy, southern France, and Turkey, are the chief silk-producing countries, to which our manufacturers are indebted for their supply of this material.

Mr. Porter states that the methods pursued by the Chinese in rearing the silk-worm are superior to those followed in Europe, and we will therefore borrow from his "Treatise on the Silk Manufacture" a brief account of this department of Chinese industry.

In those parts of the empire where the climate is favourable to the practice, the silk-worm is allowed to remain at liberty, feeding at pleasure on the leaves of its native mulberry-tree, and passing through all its mutations among the branches, uncontrolled by the hand and unassisted by the care of man, the *cocoons*, or balls of silk, being gathered when in a proper state, with the exception of those required to perpetuate the breed. The silk so produced, however, is found to be inferior in quality to that which is spun by worms under shelter, and whose growth and food have been carefully attended to. Much attention is therefore bestowed by the Chinese on the artificial rearing of the insects. One of the principal objects of care is to prevent the too early hatching of the eggs, to which the nature of the climate strongly disposes them. The mode of ensuring the requisite delay is, to cause the moth to deposit her eggs on large sheets of paper; these, immediately on their production, are suspended to a beam of the room, and the windows are opened to expose them to the air. In a few days the papers are taken down and rolled up loosely, with the eggs in them, in which form they are hung up again during the remainder of the summer and through the autumn. Towards the end of the year they are immersed in cold water, wherein a small portion of salt has been dissolved. In this state the eggs are left for two days; and on being taken from the salt and water, are first hung to dry, and then rolled up rather more tightly than before, each sheet of paper being afterwards enclosed in a separate earthen vessel. Some of the cultivators use a ley made of mulberry-tree ashes; and they also place the eggs for a few minutes either in snow-water, or on mulberry-trees exposed to snow or rain, where the climate permits of this being done.

These precautions are taken to prevent the silk-worms from being hatched before the season when the mulberry-leaves (their proper food) are in a fit state for them. When the proper time for the hatching has arrived, the rearer takes the rolls of paper from the earthen vessels, and hangs them up towards the sun, the side to which the eggs adhere being turned from its rays, so that the heat may be transmitted to them *through* the paper. In the evening the sheets of paper are rolled closely up and placed in a warm situation. The same plan is followed on the next day, when the eggs assume a greyish colour. On the evening of the third day, after a similar exposure, they are found to be of a much darker colour, nearly approaching to black; and the following morning, on the papers being unrolled, they are seen to be covered with worms. In the colder latitudes the Chinese have recourse to the heat of stoves to promote the hatching of the eggs.

The apartments in which the worms are kept are in dry situations in a pure atmosphere, and apart from all noise, which is thought to be annoying to the worms, especially when they are young. The rooms are made very close, but with adequate means of ventilation. Each chamber is provided with nine or ten rows of frames placed one above the other; on these frames rush hurdles are placed, upon which the worms are fed and kept. A uniform degree of heat is constantly preserved, either by means of stoves placed in the corners of the apartments, or by chafing-dishes, which from time to time are carried up and down the room. Flame and smoke are carefully avoided. The most sedulous attention is paid to the wants of the worms, which are fed during the night as well as the day. On the day of their being hatched they are furnished with forty meals; thirty are given on the second day; and fewer on and after the third day. The Chinese have such a strong opinion that the silk produced depends on the quantity of food eaten, that when the appetite of the worms flags, from temperature or other causes, they contrive means to excite or stimulate it artificially.

The quicker the worm arrives at maturity, the greater is the quantity of the silk produced; and hence every care is taken to hasten its development. The changes which the little animal undergoes during this time are most remarkable. In the first place, the egg from which it is produced is about the size of a grain of mustard-seed, and the worm itself, when first hatched, is a little slender thread about a quarter of an inch long. During its growth it will wander about in search of food, but if mulberry-leaves be supplied to it plentifully, it will remain stationary, occupied during the early days of its existence almost wholly in eating. When it is about eight days old, its head enlarges, and the worm becomes unwell; it remains three days without food, and in a lethargic state. In fact, its growth has been so enormous, that its skin is too tight to enclose its bulky body; and this sickness seems to indicate the period when the old skin or envelope is abandoned, and gives way to a new one more consonant with the increased size of the animal. The process is a most extraordinary one, for the insect literally creeps out of its own skin head foremost; lubricating its body to assist the extrication, fixing the skin to a mulberry-

leaf by filaments of silk spun from its mouth, and making its escape by slow degrees. The operation appears to be a painful one, for the little animals are observed to rest several times during its progress, and to be much exhausted on its completion.

When Nature has given it a more easy-fitting coat, the busy silk-worm proceeds to eat with great voracity, and increases to the length of half an inch in five days. The second coat has become by this time too small for the wearer, and is abandoned in the same manner as before. In its third stage the worm keeps on eating as before, increases in five days more to three-quarters of an inch in length, and then requires a third moulting or enlargement of skin. Another period of five days elapses, a further enlargement to an inch and a-half in length takes place, a fourth sickness supervenes, and for the fourth time the worm, finding its skin too tight for its bulky body, creeps out of it altogether, and enjoys a freer existence. This is now the fifth stage of its existence as a worm; and it proceeds to eat so voraciously (mulberry-leaves being still its favourite food), that in ten days it attains a length of two inches and a-half or three inches.

The time now approaches when the silk-worm, having received so much food from its attendants, yields more than an equivalent in the building up around him a silken wall, and spreading and arranging the thread with his front feet in waving lines around him. In this way each worm spins about three to four hun-

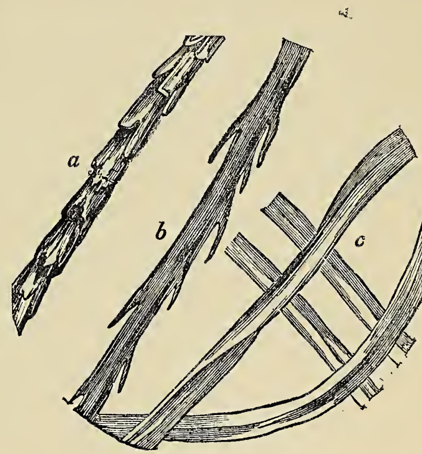


Fig. 36.—*a*, Hair of Seal; *b*, Hair of Tiger-caterpillar; *c*, Filaments of Silk; magnified.

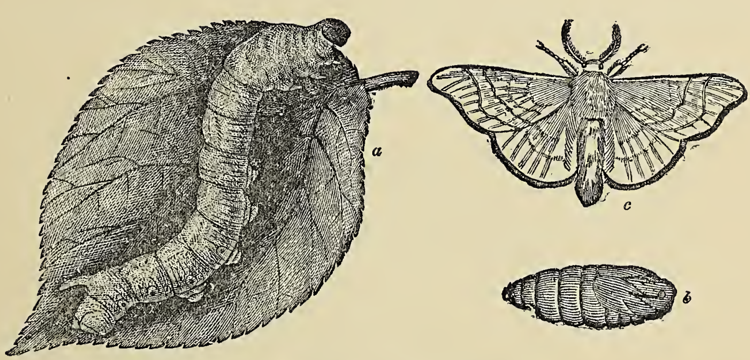


Fig. 35.—The Silkworm (*Bombyx mori*).
a, the worm feeding, and near its spinning-time; *b*, the chrysalis as taken from the cocoon; *c*, the moth as produced from the chrysalis.

form of silk. The worm ceases to eat, appears restless and uneasy, seeks about for some place where to spin its silk, and forms a sort of resting-place in some nook or corner. The body of the worm at this time contains a secretion which afterwards constitutes silk: it is a fine yellow transparent gum, contained in two slender vessels in the stomach. The worm spins or expels this gum from two small orifices in the head, uniting the two into one thread by a peculiar action of the mouth, and laying the silken thread thus formed in such a way as to build a hollow ball, nest, or "cocoon." The little spinner remains within his prison-house, dred yards of delicate silken filament, which is arranged into a hollow egg-shaped mass, measuring about an inch and a-half long by an inch in diameter.

When the cocoon is formed the insect smears the inner surface with a peculiar kind of gum, which is also used to make the silken thread cohere in making the cocoon. The animal has become by this time wasted and wrinkled, and then throws off its caterpillar state, assuming the form of a chrysalis. It remains as a chrysalis during a period of from fifteen to thirty days, and seems during this time to be preparing itself for its final stage of existence as a

winged moth. When this stage is attained the moth softens the gummy interior of its house, and gradually works for itself a hole through the cocoon, emerging at length into open day as an active but short-lived moth.

Fig. 35 represents the silk-worm in the course of feeding, the chrysalis, and the moth produced from the latter.

It will thus be seen that the silk-worm goes through many remarkable changes. It is first confined within its egg; then it emerges as a worm; then casts its skin four different times, to accommodate its increasing bulk; envelops itself in a silken nest; then changes to a chrysalis, the intervening stage between the worm and the moth; and, lastly, assumes the usual appearance of a winged insect. Their increase in size, and the quantity of food devoured by them, are quite remarkable. Fifty thousand silk-worms, when just hatched, weigh only an ounce; there are only four thousand to an ounce at the period of casting the first skin; only six hundred at the time of the second moulting; only a hundred and fifty at the time of the third; only thirty-five at the time of the fourth; and when just ready to spin, six of them weigh an ounce; so that in the period of five or six weeks, the silk-worm increases in weight nine thousand-fold! Their voracity may be thus illustrated: the worms proceeding from one ounce of eggs will consume six pounds of mulberry-leaves before their first moulting; eighteen pounds between the first and second moulting; sixty pounds between the second and

its cocoon till a proper time, and then make for itself a means of escape; but when man chooses to appropriate the silk to his own use, he puts the little hard-working prisoner to death before

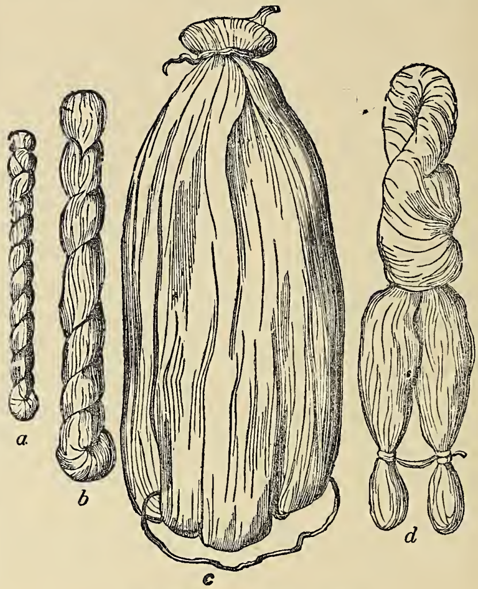


Fig. 38.—Hanks of Silk.
a, Bengal; *b*, Italian; *c*, Persian; *d*, Broussa.

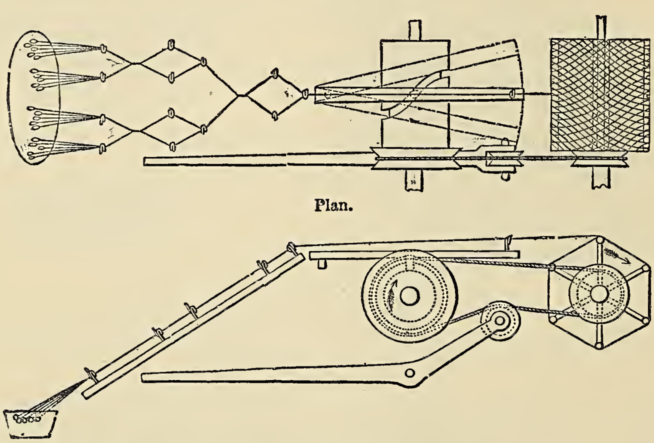


Fig. 37.—Reeling Silk from the Cocoons.

third; one hundred and eighty pounds between the third and fourth; and more than a thousand pounds between the fourth moulting and the period of spinning their silk: thus consuming, in six weeks, twenty thousand times their own weight of food!

Fig. 36 gives a comparative view of various animal fibres, together with that of silk.

If the moth be left to itself it will live within its time. The cocoons are exposed to the heat either of the mid-day sun or of an oven, until the insect within is stifled. This being done, the external soft envelope is removed from the cocoon; the former constituting *floss-silk*, afterwards brought to the state of yarn by silk-spinning; and the latter being afterwards manufactured by silk-throwing. The three or four hundred yards of filament forming each cocoon are

agglutinated together by a sort of gum applied to them by the insect; and it is necessary to soften this gum before the filament can be unwound from the egg-shaped ball. To effect this, a number of cocoons are thrown into a vessel of hot water, and there allowed to remain till the gum is softened. The reeler, or person employed, then takes in her hand a whisk, or kind of brush made of fine twigs, and presses its end gently on the cocoons. One filament from each cocoon adheres to the whisk, and is made to commence the process of unwinding. She thus gets between her fingers the thread of several cocoons, ten or twenty in number, and attaches them all to a reeling-machine. She groups them into parcels containing three or four each, then combines two of these parcels, then two of these larger parcels, and so on until all are combined to form one thread, very much thicker than the individual filament, but still an exceedingly fine thread. This thread she winds on a reel or hollow frame, replacing the spent cocoons by new ones, and having the water of such a temperature as to soften the gum just as fast as the silk is required to be wound. This process is sometimes done with the apparatus seen in Fig. 39.

The silk, as formed by the worm, is very fine and delicate; so much so, that if each cocoon was reeled separately, the thread would be useless for manufacturing purposes. This is the reason why, in reeling, the ends of the silk, in several cocoons, are joined together. It may be observed, that few persons rear the silk-worm and manufacture the silk: the breeder sells the cocoons, and the manufacturer superintends the future processes.

When the silk, after being wound on the reel, is removed from it, it forms a *skein* or *hank*, which is fastened up in a convenient form to send to market. The relation which the quantity of silk bears to the number of worms may be thus shown: supposing each cocoon yields on an average three hundred yards of silk, then it has been estimated that the original silk filament, as produced by the insect, would require nearly five hundred miles of length to weigh one pound! Two hundred and fifty average-sized cocoons weigh about a pound, and eleven or twelve pounds of cocoons yield one pound of reeled silk, the other eleven-twelfths being made up of the weight of the chrysalis, floss-silk, waste, dirt, etc. The number of insects thus required to produce any considerable weight of silk almost exceeds belief.

Mr. Porter remarked some years ago:—"The quantity of silk material used in England alone, amounts in each year to more than four million of pounds' weight, for the production of which myriads upon myriads of silk-worms are required. Fourteen thousand million of animated creatures annually live and die to supply this little corner of the world with an article of luxury! If astonishment be excited at this fact, let us extend our view into China, and survey the dense population of its widely-spread region, whose inhabitants, from the emperor on his throne to the peasant in the lowly hut, are indebted for their clothing to the labours of the silk-worm. The imagination, fatigued with the flight, is lost and bewildered in contemplating the countless numbers which every successive year spin their slender threads for the service of man." It has been calculated (and such a calculation is perhaps the best fitted to bring the matter home to familiar comprehension), that a "Gros-de-Naples" silk dress, of average size and quality, requires the labours of about *three thousand* of these little animals to produce the raw material!

The hanks of silk are of different kinds and appearance, according to the countries where they are prepared. A few specimens are sketched in Fig. 38. The silk has different tints, but all are of a golden and beautifully rich yellow, with minor variations. Broussa silk and Chinese silk are whiter than the other kinds; Bengal silk is made up into hanks or heads of small size; the Italian hanks are rather larger; the Persian, which are of inferior quality, are larger still, weighing about a pound each. These hanks constitute what is termed *raw-silk; thrown-silk* (which used to be largely imported when silk-throwing was not so much carried on in England as at present) being that which has been worked in the silk-mills.

The threads which form the hanks of silk are neither thick enough nor strong enough to be employed by the weaver or the sempstress. They are very fine, and the texture tolerably smooth. In Fig. 36, *ante*, a comparison is shown between the microscopic appearance of silk and that of two other filamentous materials—the hair of the seal, and the hair of the tiger-caterpillar. These latter two present the teeth-like serrations which (as we shall have to explain when treating of wool) give rise to the *felting* property of hair and wool. Confining ourselves, however, here to silk, it is necessary to observe that the silken filaments, in order to be prepared for weaving or sewing, require doubling and twisting and hardening. This is the class of operations carried on in silk-mills or throwing-mills. Silk-spinning is a distinct and more modern branch, of which we shall speak presently.

The introduction of silk-throwing into England was as remarkable in its way as that of silk-rearing into Europe. Until about the year 1700, all the silk woven in England was "thrown" or made into yarn in Italy; but at that time, a Mr. Crotchet, of Derby, attempted to introduce the art of silk-throwing into that town. He failed. John Lombe, a man possessed of much mechanical skill and determination of purpose, soon afterwards went out to Italy, with the view of learning the Italian method. He gathered, bit by bit, all the information necessary to his purpose; but at great personal risk, for the Italians would have resisted his attempt to the utmost, had they known it; and even with all his care he was obliged to escape precipitately from the country.

Lombe came to England, and agreed with the corporation of Derby to let him have a small plot of ground on the river Derwent, where he built a large mill. The earlier of these bold

operations were planned and executed by John Lombe; but they were ultimately carried out by his cousin Thomas, afterwards Sir Thomas Lombe. Concerning the death of John Lombe, the quaint but shrewd William Hutton, who worked at the old mill in the year 1730, gives the following account:—"Alas! he had not pursued his lucrative commerce more than three or four years when the Italians, who felt the effects from their want of trade, determined his destruction, and hoped that of his works would follow. An artful woman came over in the character of a friend, associated with the parties, and assisted in the business. She attempted to gain both the Italians (Lombe had succeeded in bringing two Italian workmen with him from Italy), and succeeded with one. By these two, slow poison was supposed, and perhaps justly,

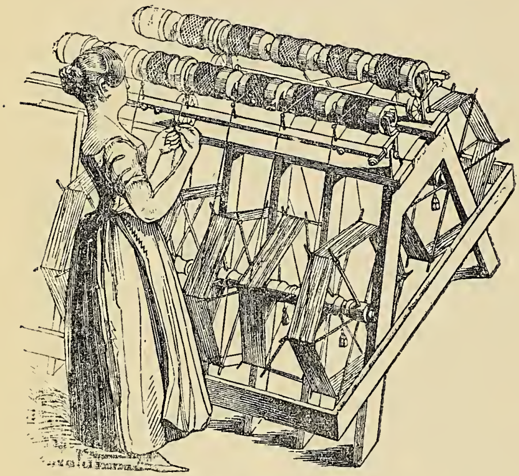


Fig. 39.—Silk-winding Machine.

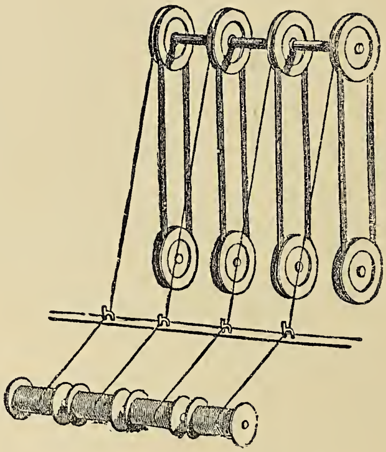


Fig. 41.—Silk-winding Engine.

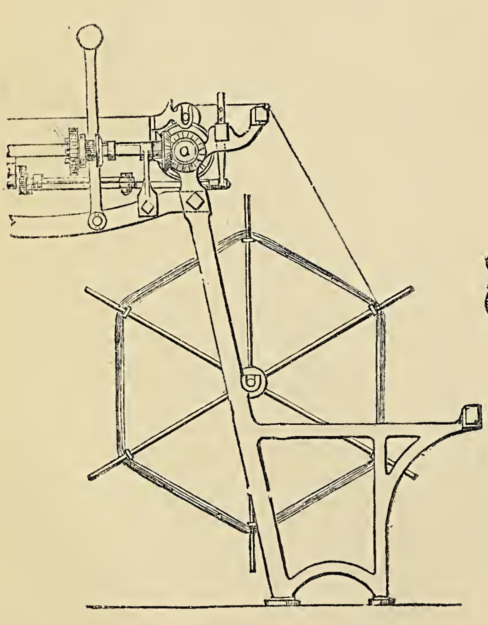


Fig. 40.—Silk-engine, or Swift.

Fig. 42.—Silk-spinning Machine.

to have been administered to John Lombe, who lingered two or three years in agony, and departed. The Italian ran away to his own country; and madam was interrogated, but nothing transpired, except what strengthened suspicion."

The processes through which the silk passes depend somewhat on the purposes to which it is to be applied. The names of *dumb-shingles*, *thrown-shingles*, *tram*, *organzine*, and *sewing* are applied to five varieties of the thread. The first, consisting of silk merely wound and cleaned, is used in weaving gauze and other light articles; the second, after being wound, cleaned, and thrown, is used for weaving into ribbons and common silk; the tram, after being wound, cleaned, thrown, and doubled, is used for the weft of the best kinds of silk goods, such as velvets, gros de Naples, and figured silks; organzine is employed for the warp of the same goods which has tram in the weft; and sewings are silken threads brought to the proper state for the sempstress. The organzine has an extra degree of twist given to it; for after being wound, cleaned, and twisted in one direction, two or more threads are doubled together and twisted in the opposite direction, something like the strands of a rope. The various processes are repeated in varying order, according to circumstances; but they comprise chiefly *winding*, *cleaning*, *doubling*, and *twisting*.

The *winding* has for its object the transference of the silk from reels to bobbins. There is, in the first place, a four-sided or six-sided frame, called a "swift," on which the hanks of silk are wound after being opened; and several of these swifts are arranged in a row in a frame, as shown in Fig. 39. Above the reels are bobbins, four or five inches long. The swifts revolve on one axis, and the bobbins on another, and when a thread is brought up from each swift to the bobbin above it, and the bobbin made to revolve, it is easy to see that the silk will be removed from the swifts, and wound upon the bobbins. This, then, is the *winding*, and while it is going forward the *cleaning* is also effected, or else in a

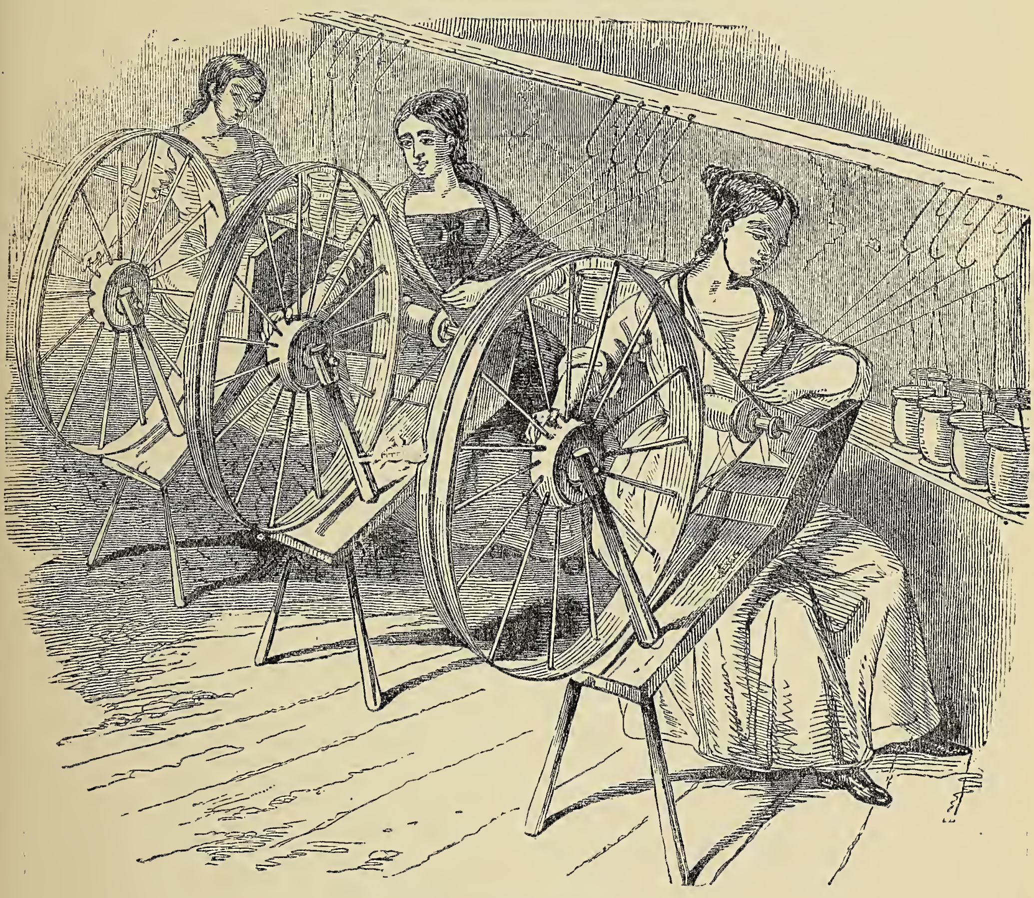


Fig. 43.—Silk-doubling.

separate machine immediately afterwards. The cleaning consists in the removal of any impurities or irregularities by which the diameter of the thread may have been rendered unequal; and it is effected by passing the silk through a cleft in a piece of steel, so adjusted in size as to allow the thread, in its proper state of thickness, to pass freely through, but to detain all asperities and inequalities. The process of winding takes part in the preparation of many textile materials, and is carried out in various ways; thus, Fig. 41 shows part of a mechanical arrangement whereby yarn or thread is transferred from bobbins to the form of skeins, or from skeins to bobbins, as the case may be; and in Fig. 42 we have a section of one of the more complicated machines used in modern factories.

The twisting of a silken thread round its own axis, to give strength and uniformity, is effected by the aid of such machines as that shown in Fig. 42. There are two tiers of apparatus here combined, one above another; but the principle of the process will be best understood by confining the attention to one only. At the top are several bobbins ranged with their axes horizontal. At a distance of some inches below them are other bobbins ranged with their axes vertical, and the silken threads are conducted downwards from the former to the latter. There is a kind of loop or eye which aids in winding the thread equally on the vertical bobbins. Now the peculiar action of these two sets of bobbins, one upon another, is this: when both sets of bobbins are revolving, or rather, the upper bobbins and the loops of the lower ones, the thread becomes unwound from the upper ones, and wound upon the lower. But this is not all. In order that the thread may conform to the difference of rotation, first horizontally and then vertically, it becomes *twisted*, like the spiral form of a rope; and it is this twist which is the object of the process. If, while the upper bobbins maintain a regular rate of movement, the loops of the lower ones increase the rapidity of their rotation, the twist becomes harder, closer, or with a larger number of spiral turns in a given space; and by governing the relative velocity of the two movements any required closeness can be given to the twist.

The *doubling*, as we have stated, consists in combining two or more threads together, and twisting them around each other. It is effected sometimes by a machine of rather complex arrangement, and at other times by a sort of hand-wheel (Fig. 43). In the latter method, there are fixed up near a hand-wheel as many bobbins as there are to be threads doubled together. The ends of all the threads are taken up between the fingers of the doubler, passed through a sort of loop, and attached to the wheel. Then, by turning the wheel with the right hand, all the threads become doubled, or laid side by side.

The threads so doubled, in order to have coherent strength given to them, require to be "twisted," or "thrown" around each other, an operation very similar in principle to that of the previous twisting. The doubled threads are wound on a sort of open framework or long horizontal reel (Fig. 43), and the ends of the various threads, after being carried through eyes or guide-pins, are attached to rotating flyers or loops. The action, then, is the same as before: the silk, in the act of exchanging a horizontal rotation for a vertical one, becomes twisted, all the component threads being coiled round each other. The direction of this twist has something to do with the purpose to which the thread is to be applied. In the making of "tram," the silk is not twisted immediately after being wound, but the raw silks are doubled, and then twisted to the right hand; for "organzine," the raw silk is wound, then twisted to the left, then doubled, and the doubled thread finally twisted to the right.

Sometimes silk is twisted in nearly the same manner as ropes are made, that is, in a long alley or gallery, with a wheel at one end of it. This occurs when the silk is required to be made very dense, thick, and strongly twisted. On one face of the wheel (Fig. 45) are ten or twelve hooks ranged near the circumference. Threads of silk are fastened at one end to these hooks, and at the other to a set of hooks fixed in a frame resting on the ground. A handle sets in rapid revolution all the hooks attached to the wheel; and this movement causes the several threads to twist very closely, each one around its own axis. Boys run to and fro to attach and detach the threads.

It is by such a series of processes, comprising chiefly winding, doubling, and throwing, that the silken filaments are brought into a fit state for dyeing, or for weaving, or wearing.

As to *silk-spinning*, this is a very different branch of manufacture. It is applied to "floss-silk," to the silk of defective cocoons, and to the waste silk produced in any of the processes. If the silk cannot, for any reason, be worked out into an extended and unbroken thread, it is destined for the silk-spinning mills, where it is treated almost exactly in the same way as cotton, being carded, drawn, roved, and spun. It is an inferior kind of material, and is used in making cheap silk shawls and handkerchiefs, intended to look well, and yet to be sold cheap. Fig. 46 shows a vertical sketch of one of the complicated pieces of apparatus now employed in this department of the silk manufacture.

As in the case of cotton, we shall postpone the consideration of the arts relating to the dyeing and weaving of silk, till we can take up all the four great classes of fibrous materials together.

WOOL.

In the Introduction to this work, a short notice has been given of the early history of woollen manufactures generally. So far as our country is concerned, it would appear that the known history of our woollen manufactures dates back nearly 2,000 years. Mr. P. L. Simmonds, in an historical sketch, appended to the catalogue of the Woollen Exhibition held at the Crystal Palace in 1881, remarks:—"When Cæsar invaded Britain, he found the inhabitants of the

southern portion of our island well acquainted with the spinning and weaving of both flax and wool. Two kinds of cloth were manufactured at this period, and both were highly prized by the invaders—one a thick harsh cloth, which was worn as a sort of mantle; the other of finer wool, dyed different colours, and woven chequered, after the manner of the Highland tartans. According to Camden, the first woollen factory appears to have been established by the Romans, at Venta Belgarum of the ancient Britons, named by the Romans Winchester, about one hundred years after the conquest of the country. The woollen manufacture gradually spread northwards, with varying fortune, but on the departure of the Romans it suffered greatly.

"Woollen garments formed almost exclusively the attire of the Romans, male and female, of every rank. After the downfall of the Roman empire, the cloth manufacture, which had been —with all the other arts of civilised life— involved in a temporary ruin, began first to revive about the middle of the tenth century in the Low Countries, where it continued to bestow peculiar opulence, freedom, and consideration on the people for several hundred years.

"On the departure of the Romans the arts also took flight, and left the English for upwards of one thousand years to clothe themselves in skins. Even George Fox, the founder of the Quakers in the reign of Charles I., travelled as a missionary through the country, buttoned up in a leathern doublet with sleeves, instead of a cloth coat, this being the common dress at the time of labouring mechanics, the class to which this gifted individual belonged.

"Whitaker, in his history of Manchester, says: 'It is recorded that the mother of Alfred the Great was skilled in the spinning of wool, and trained her daughters to the same pursuit. Spinning with distaff and spindle formed the employment, nay even the recreation, of the noblest of the land, and we read that the daughters of King Edward the Elder employed themselves in spinning, weaving, and embroidery.'

"It is common to assume that the manufacture of cloth was wholly lost here during the Norman era, until re-established by Edward III. But although the land—racked by successive struggles against invaders and torn by internal warfare—was probably worn out at the Conquest, its commerce ruined, its industries enfeebled, yet mention of home-made fabrics during this period occurs so frequently among its scanty records, that comparative excellence must surely have been again attained.

"A twelfth century historian says of the English in his time that they were 'a people most versed in woollen manufactures and merchandise.' In A.D. 1112 particulars are given of a number of Flemings—'a brave, hardy people, equally qualified to handle the plough and the sword, and they were also skilful in the woollen manufactures, the great staple of their country'—being driven to England by successive inundations of their land, and coming in such numbers as to be a burden to the natives. They were first sent to settle on waste lands in the north, particularly about Carlisle, where they may perhaps have found kindred, as it is said that a similar immigration of Flemings took place in the time of the Conqueror. Sir Matthew Hale says: 'In the time of Henry II. and Richard I., this kingdom greatly flourished in the art of manufacturing woollen cloth.'"

Mr. Simmonds traces the history of the English wool manufactures with much minuteness, but to an extent that does not permit our introducing it into these pages. He gives some very interesting archæological details, from which we select the following:—

"A journal devoted to the textile industries furnishes some curious archæological information respecting the woollen trade. In the Middle Ages there was annually, on the feast of Corpus Christi, a grand pageant in the City of York, in which were represented the various trades carried on in the county of broad acres. From the record of these pageants it appears that the wool-packer took an important position in the celebration. The term indicates the nature of his employment. Into his hands the fleece was delivered. No trace is left of the wool-sorter in the old records, but in the next process we meet with the pynner—that is, comber—the word pynner being evidently an Anglicised form of the Norman-French word *peinnur*. At first sight it may appear strange that there should be no record of the spinner, but women's rights were not to the fore in those dark ages, and it will at once occur to the mind that spinning was a feminine occupation, carried on at the fireside, and there still remains the appellation given to women who spun in the modern word *spinster*. The extension of trade brought about a change in spinning, and it was gradually transferred to the male sex, but no special period for the transaction can be stated. There is, however, in an old list of the fourteenth century, reference made to 'spynsters, carders, and cappe-knitters,' who were men. Weaving also was, in the early stage of the cloth trade, executed by women. Thus we find in the Visions of Piers Plowman, the lines, 'My wyfe was a webbe and woolen cloth made.' To persons who are fond of tracing the changes words undergo, the spelling of 'woolen' will not be overlooked, and it will also be seen that the American mode of spelling the word with only one 'l' is simply a return to the original form. From the makers of webbe is obtained the word *webber*, and its feminine form *webster*. Here again occurs an interesting word. Webster originally meant a female webber, but in course of time the occupation of the workwoman became the surname of her descendants, and thus the large family of the Websters now engaged in the Yorkshire cloth trade can trace back their ancestry to the women-weavers of mediæval times. But as trade advanced the fraternity of weavers became an important body in the community."

It will be interesting to note the early history of the woollen manufactures in Halifax, now one of its centres in this kingdom.

"'Wool-drivers,' or buyers, having been abolished by statute, it was found so seriously to interfere with the trade of some of the districts that, in 1555, an Act was passed allowing 'wool-driving' to go on as heretofore. The preamble was very curious; it stated that 'Forasmuch as the parish of Halifax, and other places adjoining thereto, being planted in the great wastes and moors, where the ground produces neither corn nor good grass, but in rare places, and that by the great industry of the inhabitants; and that as the people live altogether by cloth-making, and that many neither get corn nor are able to keep a horse to carry their wool, nor yet to buy much wool at once, but have always resorted to Halifax, and places nigh thereto, and there to buy of the wool-drivers, some a stone, and some two, some three or four, according to their ability, and carry the same to their houses—some three, or four, and five miles, and some six miles—upon their heads and backs, and so to make the same into yarne or cloth and sell the same, and so to buy more wool; by means of which industry the barren grounds have been inhabited and five hundred houses have arisen; and as there is now great danger of the manufacture being destroyed, and the people with it,' that therefore the 'wool-driver,' who had been abolished by recent statute, was to be replaced, 'that he may sell, in the

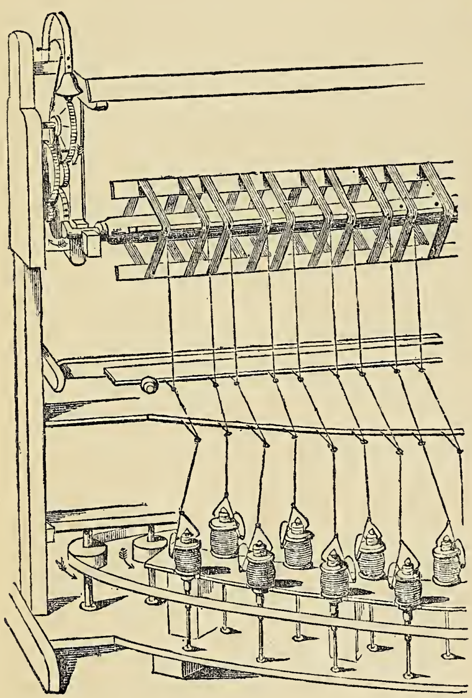


Fig. 44.—Silk-throwing Machine.

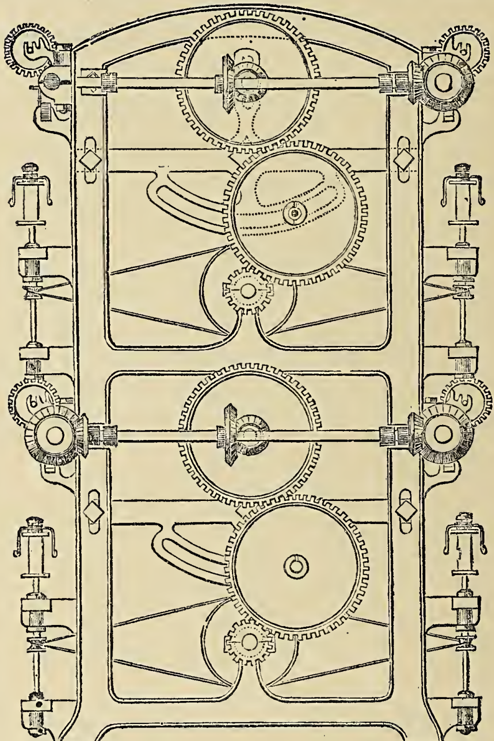


Fig. 46.—Silk-spinning Engine.

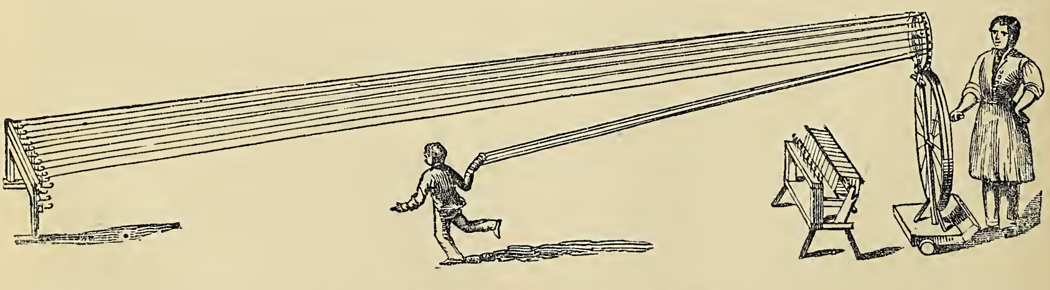


Fig. 45.—Silk-throwing, or Spinning by Hand.

town of Halifax, to these poor people, wool to make into yarn or cloth, but not to sell again.'''

In regard to the operations of "fulling," teazling, etc., Mr. Simmonds gives the following interesting particulars :—

"An important process in manufacture is that of fulling, and in the trade lists frequent mention is made of the fuller. In early times no machinery was used in fulling cloth, and, consequently, we obtain the explanation of the reason why a fuller is oft-times called a walker. It was the walker who thickened the cloth by treading it. As in other trades, the introduction of machinery was resisted, partly on account of the displacement of the walker, and partly because it was asserted that hand, or rather foot, labour was more efficient. In the reign of Edward IV. it was represented to that monarch that 'hats, caps, and bonnets had hitherto been made, wrought, fulled, and thicked in the wonted manner, that is to say, with hands and feet, but the use of mills had brought inferior articles into the market.' It will be remembered that these articles of dress were, at that period, made chiefly of woollen cloths, although silk and velvet head-gear were the adornments of the wealthy. The use of teazles in raising cloth is very ancient. Langland speaks of cloth 'with teazles cracched.' The workman was called a tawseler, the old form of teazles being tayseld. In days when the law regulated almost every department of manufacture, we find that by an old statute 'every fuller, from the feast of St. Peter, in his craft and occupation of fuller, rower, or tayseler of cloth shall exercise and use taysels, and no cards deceitfully impairing the cloth.' The next process was that of dyeing. Here we meet with a number of names applying to the same workmen, such as litster, dyer, dyster, dister, and then, apparently for the same reason as a tradesman calls his shop an emporium, some dyers dignified themselves as tinctors, which became corrupted into tentiers. Connected with these names there are many points of interest. We have already mentioned how the Websters of the West Riding came by their name, and now we see the origin of the Lysters and Listers, common names in the district. The tentier explains a feature in the West Riding landscape. Every one who is

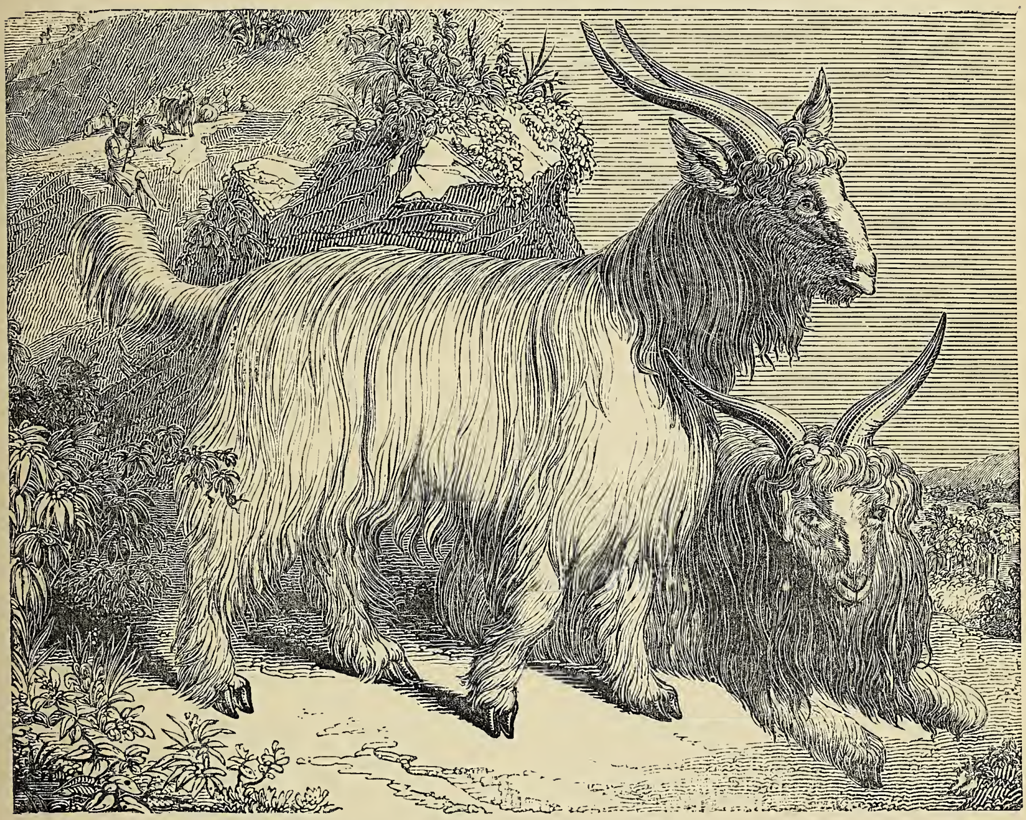


Fig. 47.—Shawl-wool Fleece of the Cashmere Goat.

acquainted with the district has noticed the rows of posts still to be seen in many open spaces. These are the memorials of the tenters, and also record the care taken to prevent fraud. Various devices have been contrived to overreach either buyer or seller. The merchants' thumb is still a bye-word in the clothing district. In days gone by the law intervened to prevent the over-stretching of cloth after dyeing, by insisting upon public tenters being provided at the expense of the township. To the places where the public tenters were set up the term 'close' was applied, and now even where the tenter posts are no longer to be seen the term 'Tenter's Close' survives in the locality. The drysalter of the Middle Ages went by the name of wadman. It was he who sold the dyewares, principally woad, to the dyers; hence his name, although he included madder in his articles of trade."

Such are some interesting particulars which Mr. Simmonds has collected in reference to the early history of our woollen manufactures. Its modern condition will appear as we describe the various processes at present followed.

Most of all the productions from wool are divisible into two great classes: those in which *short wool* is employed, and which come under the denomination of *woollens;* and those in which *long wool* is used, known as *stuffs* or *worsteds.* It is true that this subdivision is not strictly exact in all instances, but it is sufficiently so for our object. Generally speaking, *broad cloth* may be taken as a type or exemplification of woollens, and *stuff* of worsteds; but the varieties are very great. Thus—*blankets, flannels, stuffs, merinos, mousseline de laines, shaloons, says, moreens, calimancoes, camlets, lastings, baize,* and many others, are examples of long-wool manufacture, modified in various ways; *broad cloths* are examples of plain weaving, and *kerseymere* of twilled weaving, in the short-wool manufacture; *serges* are twills, having worsted warp and coarse woollen weft; *bombazeens* are a twilled mixture of worsted and silk; *poplins* are an untwilled mixture, showing more silk at the face and more worsted at the back; the modern cloths, called *Saxonies* and *Orleans,* are made of unfulled woollen, sometimes mixed with cotton; *stuffs* are made wholly of worsted; *merinos* are a fine woollen twill, sometimes printed; *Cashmeres,* if real (which is seldom the case), are made from the hair of the Tibet goat, but are generally made of sheep's wool; *challis* have a silk warp and a woollen weft, and are generally printed; *mousseline de laine* was originally (as its name, "wool muslin," implies) all wool, but very frequently contains cotton; *Norwich crape* is formed of wool and silk, *Crêpe de Lyon* of worsted and silk. It would be impossible to enumerate all the varieties which modern art has introduced in the admixture of woollen, worsted, silk, and cotton in the same piece of goods. The two distinctions, however, in respect to wool, will be sufficiently kept in mind by designating them *clothing wool* and *hosiery wool,* since hosiery was the primary purpose to which long wool or worsted was applied.

Before we notice the routine of industry in these branches, it may be well to say a word or two respecting the kind of goods manufactured in the East, because many of these are made of goats' hair rather than of sheep's wool. From a very early time, as we had occasion to observe in a former page, the manufacture of woollen goods has been known and carried on by many nations among the Asiatics. Some of the breeds of sheep are very remarkable; but it is principally to the hair of goats that the celebrity of the Eastern manufacture in these matters has been due. Many of the wilder animals, such as the beaver, the racoon, the wild-cat, and the otter, produce both hair and wool, the hair forming the long and conspicuous outer fibres, and the shorter fibres of wool lying hidden beneath them. It is, as we shall presently see, in the different power of the different kinds of wool or hair to become *felted,* or matted together, that the manufacture takes its peculiar cast. One or two examples of the kind of hair-wool manufactures of Asia will sufficiently illustrate this part of the subject.

The persons who, in our own country and at the present day, purchase worsted or woollen goods under the denomination of *Cashmeres,* are or ought to be aware that such goods are Cashmerian only in name. A real Cashmere shawl, made by the inhabitants of that Indian valley from the wool of a peculiar variety of goat reared on the plains of Tibet, is a most costly article, eagerly sought after by the rajahs and sultans of the East, but finding its way to Europe very rarely indeed. To make a pair of large and handsome Cashmere shawls requires the labour of twelve or fourteen men for half a year. The late Runjeet Singh, the chief of Lahore, gave five thousand rupees for a pair of these woollen shawls, the patterns of which represented his victories. The animals from which the material is obtained (Fig. 47) are covered by nature with two kinds of coat or clothing: the one fine, curly, generally grey, and imparting to the skin a down more or less thick, as if to guard it against cold and damp; the other coarse, lank, and giving a general colour to the animal; and as it is only the inner and finer coating which is used for the fine shawls, the quantity produced is very limited, and therefore high priced. The down, called *poshm,* is collected from flocks of goats on the plains of Tibet, and brought to the confines of Cashmere on the backs of sheep; it is then cleaned, and one-fourth of it (being all that is fitted for the shawls) is carried on men's backs the remainder of the distance to Cashmere. When arrived at Cashmere, it passes into the hands of the merchants, who sell it in small quantities to the weavers at the rate of about two rupees per pound. The thread is dyed a great variety of colours, then stiffened with rice-water. Various articles are woven with these coloured threads, the process being slow and tedious on account of the rude construction of the looms. Shawls, coverlets, handkerchiefs, turban-pieces, gloves, socks, and other garments are woven of this *poshm.* The shawls are washed

after being woven to remove the rice-stiffening, and a fine pale yellow colour is imparted by means of sulphur-fumes.

The trade in shawls at Cashmere is rather a curious one. M. Vigne, in his "Travels in Cashmere," thus describes it:—"The *mokym*, or broker, who transacts business between the shawl manufacturer and the merchant, is a person of great importance in the city; and the manner in which their transactions are carried on is singular. They have correspondents in most of the larger cities of Hindustan, whose business it is to collect and forward every species of information connected with their trade. By their means they seldom fail to hear of any *sandagur*, or merchant, who is about to start for Kashmir; even from such a distance as Calcutta; and, if he be a rich man, the mokym will send as far as Delhi to meet him, and invite him to become his guest during his sojourn in the valley. Perhaps again, when the merchant, half dead with fatigue and cold, stands at length on the snowy summit of the Pir Panjal, or either of the other mountain passes, he is suddenly amazed by finding there a servant of the broker, who has kindled a fire ready for his reception, hands him a hot cup of tea, and a kabab, a delicious kalioun, and a note containing a fresh and still more pressing invitation from his master. Such well-timed civility is irresistible; his heart and his boots thaw together, and he at once accepts the hospitality of the mokym, who, it may be, is awaiting the traveller, with a friendly hug, at the bottom of the pass, two or three days' journey from the city, to which he obsequiously conducts him. He finds himself at home at the house of his new friend, and himself and servants studiously provided with all he can require. His host, of course, takes care to repay himself in the end. He has an understanding with the shawl manufacturers who frequent his house, so that the guest is at the mercy of both parties; and should he quarrel with the broker, and hope to make a purchase without his intervention, he would find it impossible. No shawl-vender can by any possibility be induced to display his stores until the approach of evening, being well aware of the superior brilliancy imparted to their tints by the slanting rays of the setting sun; and when the young sandagur has purchased initiation by experience, he will observe that the shawl is never exhibited by one person only; that the broker, perhaps, apparently inattentive, is usually sitting by, and that under pretence of bringing the different beauties of the shawl under his more especial notice, a constant and free-masonic fire of sneezes and pinches, having reference to the price to be asked, and graduated from one hundred to a five-rupee power, is secretly kept up between the venders by means of their hands extended under the shawl. When the merchant has completed his purchase, the mokym, who was before so eager to obtain him as a guest, pays him the compliment of seeing him safe to the outside of the city, where he takes leave of him at Chartubal, the very last place within it."

Other districts of Asia in like manner produce flocks of goats or of sheep, which have given rise to manufactures among the neighbouring inhabitants. One other example will suffice here to illustrate this matter.

A paper was read before the Asiatic Society several years ago, from Lieutenant Conolly, on the manufacture of woollens from the wool of the Angora goat of Asia Minor, in which some of the details are curious. The natives call this goats' hair by the name of *tiftik*, while sheep's wool is called *yapak*. When the *tiftik* fleeces have been shorn, the women separate the clean from the dirty, pass it through fine-teethed iron combs, and spin it into thread; while spinning they moisten the hair with spittle, which they prefer in the melon-season, as the saliva becomes more mucilaginous when this fruit has been eaten. "Before this yarn is used by the weaver," says Lieutenant Conolly, "it is well saturated with a glutinous liquor called *chirish*. This is made from a root like a radish, which comes to Angora from the neighbourhood of Conia. It is dried and pounded, mixed with dates, and well shaken in a bag; then the liquor is strained off, and small skeins are steeped in it; while large hanks are watered by the mouth when they have been spread out, according to the following process, which I may describe as witnessed by us at Angora:—We found the workmen before sunrise on a level space by the banks of the Angora stream. Upon a centre and two end cross-trees was rather loosely stretched a double web of yarn, seventy feet by seven, which was kept extended and separate by sliding cross-sticks. Two men walked up and down the sides of this frame at the same time, nearly opposite to each other, holding bowls of chirish liquor, made into a thin yellow mucilage; of this they continually squirted, or rather blew out mouthfuls in alternate showers, all over the web; while others followed them, to press the threads together for a moment, and then to change their position relative to each other, by means of the sliding cross-bars mentioned, so that all might be equally moistened, as well as to rebind any threads that had given from the tension. The chirish liquor had a sweetish and not unpleasant taste, but the squirters complained that it totally destroyed their teeth, and showed bare gums in proof. They distributed their jets with singular dexterity, in broadcasts of the minutest drops; and expressed doubts whether, considering the clammy nature of the liquor used, any watering-pot could be made to do their work as well, and save them from its inconvenient effects. This operation is repeated several times; the work is always commenced in the cool of the morning, so that it may be completed ere the heat of the sun can operate to dry the thread quickly. . . The women of Angora knit gloves and socks with the *tiftik* yarn, making them both furry and plain, and making some socks of the better sort so fine as to cost one hundred piastres the pair. The surplus of their yarn they sell to native weavers of stuffs. The weaver seeks threads of equal

thickness, and takes the skeins that he matches back to the women spinners, who reel them into one thread, assisting their operations with *chirish* mucilage. The connected thread being returned to the weaver in hanks, he with a hand-wheel winds on small portions through a pan of water on to bits of reed cut to fit his shuttle. In regard to the varieties of wool employed in the manufacture much will be said hereafter. It may be here remarked, however, that we are now chiefly indebted to our colonies at the Cape, Australia, and New Zealand, whence enormous quantities of wool are exported to this country. The following table, furnished in Mr. Simmonds's work, gives the importations from abroad from 1860 to 1880 inclusive :—

Countries.	1860.	1870.	1880.
British Possessions.	Lbs.	Lbs.	Lbs.
Australasia . .	59,166,000	175,081,000	300,240,000
India . . .	20,214,000	11,150,000	29,052,000
South Africa . .	16,574,000	29,220,000	51,457,000
Foreign Countries.			
European States .	38,862,000	24,329,000	55,635,000
South America .	8,950,000	9,000,000	24,000,000
Other Countries .	4,630,000	18,861,000	
Total Foreign and Colonial Sheep and Lambs' Wool . .	148,396,000	257,641,000	460,338,000
Sheep's Wool, Estimated Home Production . . .	100,000,000	160,000,000	150,000,000
Skin Wool, Estimated from Imported Sheep	1,000,000	2,400,000	4,000,000
Woollen Rags Imported . . .	17,029,000	38,550,000	92,279,000
Goats' Hair . .	2,822,000	3,079,000	13,203,000
Alpaca . . .	2,000,000	3,889,000	2,548,000
	271,247,000	465,559,000	722,368,000
Reimported of all kinds . . .	42,015,000	106,360,000	254,569,000
Left for Consumption and in Stock . .	229,232,000	359,199,000	467,799,000

It appears that the wool clip of the wool has increased fourfold since 1830, when it was only about 320 million pounds; now it exceeds 1,600 million pounds.

An eminent authority has remarked that "The climate of Australia has proved itself to be highly favourable to the breeding of fine-woolled sheep, and its influence, combined with care and skill in the management of the flocks, has greatly improved the quality of the Merino breed. The wool has retained its great fineness and acquired a remarkable lustre and softness, while its length has been greatly increased. The even clothing of the whole body and points of the sheep has been attended to by breeders, so that a remarkably heavy fleece is now obtained, both weight and general quality showing a decided improvement upon the results of former years. Not only has the value per pound and the weight of fleece been doubled, in some instances, by the improvement of the breed of the best flocks, but the experience which has been gained in the washing of the wool has had a material effect in increasing the profitableness of sheep-breeding. English sheep have been introduced to the Australian colonies, and the Lincoln and Leicester breeds have been found very useful in the cooler and more moist districts; but the Merino has received the greatest attention, as being most suitable for profitably stocking the larger portion of the continent. Not only in New South Wales, Victoria, and Tasmania have pure Merino flocks been established, but in Queensland and New Zealand that breed of sheep is being extensively introduced, while there is no doubt that Western Australia will yet prove a good sheep country.

"The quantity of wool exported from Australia and New Zealand in 1879 amounted to 313,274,336 lbs., valued at £15,901,789. Of that quantity New Zealand contributed 62,220,810 lbs., valued at £3,126,439; New South Wales, 123,710,450 lbs., valued at £6,491,198; Victoria, 47,973,091 lbs., valued at £2,653,528; South Australia, 49,402,149 lbs., valued at £1,984,879; Queensland, 22,582,834 lbs., valued at £1,238,518; Tasmania, 7,585,002 lbs., valued at £407,227. The average weight of wool obtained from each sheep in Australia has greatly increased within the last twenty years. In 1860 the average was 2·94 lbs. per sheep of greasy, and 1·70 lb. of washed wool; in 1870 the average was 3·52 lbs. greasy, and 2·29 lbs. washed; and in 1877 the yield had increased to an average of 4·29 lbs. per head greasy, and 2·36 lbs. per head washed. These averages are only approximate, but there is no doubt that a great improvement has taken place in the time mentioned in the weight of fleece. Although so much has been done to improve the flocks of Australia, there is still much more to do. In the exigencies of pioneering and the taking up of new country, second-rate or inferior sheep are often the only kinds obtainable, and the consequence is that the largest portion of the stock at present is far from being pure-bred. Those inferior sheep are occupying country which could as easily support flocks that would produce at least twice as high a return to the owners; so that it is within the mark to estimate that the value of the exports of wool could be greatly increased by the improvement of the present flocks, without increasing their numbers. In addition to the development which is possible in that direction, there is an almost unlimited field in the stocking of those extensive tracts of the continent which are at present occupied by less profitable kinds of stock, or still awaiting the arrival of the settler. It is a comparatively limited portion of the earth's surface that is suitable for producing the finest quality of wool, and the demand for fine woollen fabrics seems to be increasing with the spread of civilisation. Possessed of extensive tracts of fine pasture-land in the favoured wool-producing climate, and having already laid the foundation of the finest flocks in the world, there should be a brilliant future before the sheep-breeders of Australia. When there is little danger of over production, and the highest prices in the markets

of the world are already commanded, the wool-growing industry is entitled to receive all that attention which is necessary to enable it to maintain its position and develop itself to the fullest extent. The extensive and suitably arranged wool stores of Melbourne, combined with the central position of the capital of Victoria, have done much to encourage annual wool sales here. Those sales are now attended by European and American buyers, and it will no doubt soon become the rule for purchasers to attend a market where they can obtain a choice of so many fine samples. The assistance rendered to the wool-producing industry in the direction of making European and American buyers better acquainted with Australian wool in its native climate will not be the least of the good results of the Melbourne International Exhibition." The preceding remarks have been extracted from the catalogue of the International Wool Show, held in January, 1881, in connection with the Melbourne (Australia) Exhibition. The entire report afforded a digested account of the origin and progress of the Australian wool trade.

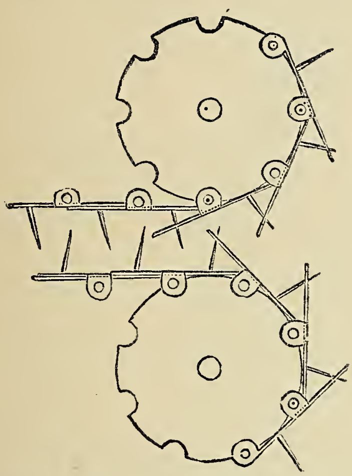


Fig. 48.—Wool-combing Machine.

Having thus traced the history of the woollen manufactures in this country, and named the chief sources of our supply of the raw material, the practical processes must next be described by which the wool is converted to yarn, worsteds, cloths, etc.

When the locks of wool have been opened and sorted, and the dirt and dust allowed to separate from them, they are washed in a hot liquor calculated to remove the grease which the wool had imbibed from the sheep. This done, the disentanglement of the fibres is effected by a machine, exactly the same in principle as the "willow" employed in the cotton manufacture. It is called sometimes a "willy," sometimes a "devil," but always consists of a revolving machine, containing spikes which tear asunder the locks of wool, leaving the fibres more or less disentangled. Some kinds of wool require to be willowed more than once, to effect the disentanglement; while all of it needs a little lubrication with oil, to soften and render it more workable.

The next stage is to lay these fibres in a parallel and even direction, preparatory to the spinning operation. The principle involved bears a close resemblance to that of the preparation of cotton; since, in the one case as well as in the other, there are fine fibres lying crosswise in a confused manner, and requiring to be brought all into one direction, equable and regular: the difference of the fibrous structure leads to variations in detail which will be noticed as they occur. There are several machines involved in this preparation of wool—the "scribbling-machine," the "carding-machine," and the "slubbing-machine." In that variety of the wool-manufacture which relates rather to worsted or long wool than to clothing-wool, the fibres are brought out straight by a kind of *combing*, in which machines (two forms of which are shown in Figs. 48, 49) are employed.

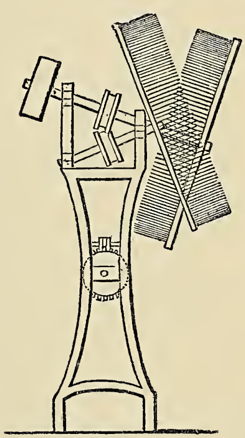


Fig. 49.—Wool-combing Machine.

This matter, however, will come on for notice a little farther on. We may here briefly explain, that of the three preparing machines necessary for clothing-wool, the "scribbling-machine" consists of a system of cylinders, on the surface of which are numerous points or teeth, bent in particular directions, and acting near each other. A girl takes the oiled wool by handfuls, and lays it on a kind of apron or cloth attached to the machine. This apron moves onwards, and the wool is caught by the teeth of the first cylinder, carried round, caught a second time by another set of teeth, carried round still further, and so on; being disentangled and opened by every transference from one cylinder to another; until at length it leaves the machine in the form of a light flocculent layer, all the fibres

being disentangled, but no approach being yet made towards the parallel arrangement of the fibres.

The "carding-machine," or card-engine (Fig. 50), like the similarly-named piece of apparatus employed in the cotton manufacture, completes the work of the scribbling-machines, by giving to the fibres of wool a parallel and uniform arrangement, and also rolls them up into a pipe or cylinder. An attendant in the first place weighs the wool accurately, according to the quantity required for any particular stoutness of cloth, and lays it on the feeding-aprons of the machine, from whence it is drawn in to be acted on by teeth, as in the former case. The teeth comb it out to a regular form, and at the same time fashion the mass of fibres into detached flat layers or bands. Each of these delicate bands is, by a remarkable adaptation of the machine, rolled up into a rod or solid pipe, with a thickness varying from a quarter to half an inch. This roll is very curiously formed; for an inspection of its structure shows that the fibres do not run *lengthwise* of the piece, but across; so that the roll may almost be considered as a succession of rings. Such an arrangement would be utterly inconsistent with the requirements of the cotton manufacture; but in the case of wool, the peculiar property of *felting* (to which we shall presently have occasion to allude more particularly) is brought more fully into action by it.

These rolls of wool are called "cardings;" and the operation of the next piece of machinery, the *slubbing-machine*, or the *slubbing-billy*, is to connect all these cardings into a continued roll called a "slubbing." The reader has probably by this time had many inducements to smile at the odd designations which workmen are wont to give to the machines employed by them—the "jenny," the "billy," the "mule," the "devil;" "scribbling," "throstling," "throwing," "slubbing,"—all are examples of nomenclature which it would be somewhat difficult to account for. The slubbing-billy takes part in a curious train of operations. There is at one end of the machine, in its old form, a sloping board, on which the rolls or cardings of wool are laid side by side, by young boys called "pieceners." By the action of the machine these cardings are caught up, drawn in, and so elongated by a kind of spinning-process, as to be reduced in thickness to a cord about one-twelfth of an inch in diameter. Each carding, originally about a yard long, becomes elongated to several yards; but it would still be a piece of only determinate length, were not arrangements made to add carding to carding as the operation proceeds. It is the office of the "pieceners," therefore, to place new "cardings" on the sloping board before the whole of those previously applied have been drawn in, and to squeeze the ends of the one set to those of the other, sufficiently to enable them to cohere. The result of this is that a continuous cord or loose string is formed, as long as the pieceners keep up a supply of new cardings. At the right-hand side of the machine is a wheeled carriage or frame, something like that employed in the "spinning-mule," and having a row of spindles upon it. By the management of a handle turned by a workman, and by moving the carriage to and fro, the "cardings" are stretched into "slubbings," and those slubbings are wound in the spindle. Great improvements have been made on this method, and the most advanced of these were shown at the Wool Exhibition at the Crystal Palace in 1881.

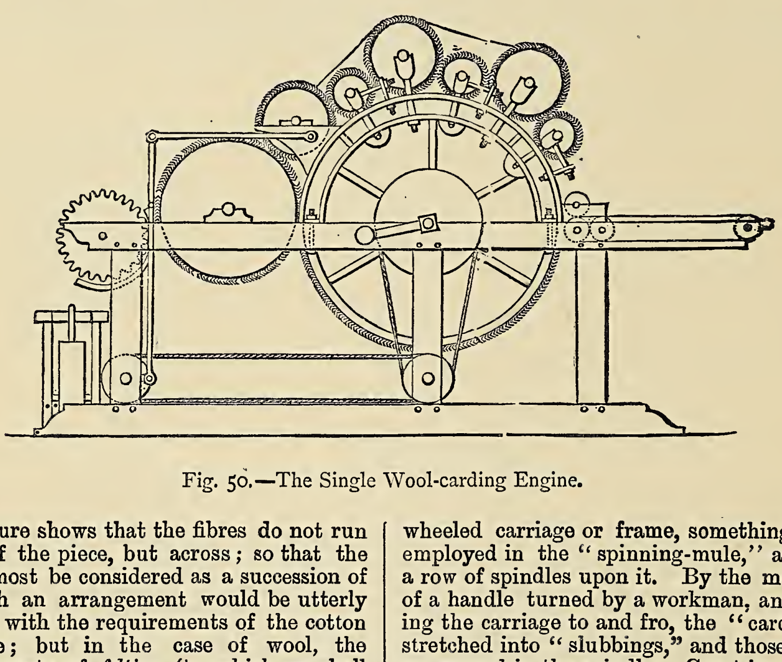


Fig. 50.—The Single Wool-carding Engine.

Here, then, we have brought the wool to the state of a loose cord, an ounce of the material forming from one to two hundred yards of the cord, according to its thickness. This is analogous to the "rovings" of the cotton manufacture, and is next spun into yarn by machinery and processes bearing so near a resemblance to those before described as to render particular description unnecessary, more especially in regard to mule-spinning, described in regard to cotton, at page 19, *ante*.

When the woollen yarn is spun, it is handed

over to the weavers, whose labours will shortly come under our notice; and, when woven, the woollen cloth goes through a train of finishing processes, to which a little attention may now be paid. It may be well to state here, in reference to the *colour* of the wool, that certain differences are observable between cotton and wool in respect to dyeing. Cotton goods are never dyed while yet in the state of loose unspun wool; they always receive the colours artificially imparted to them, either when in the state of yarn before weaving, or after being woven. In the case of wool, however, the material is not dyed in the state of yarn; it is dyed either in the raw state, before spinning, or in the finished state after weaving. This difference gives rise to the two designations of "wool-dyed" cloth and "piece-dyed" cloth, according to the period in the operations when the dyeing is effected. With this difference, the processes subsequent to weaving are pretty much alike in both cases.

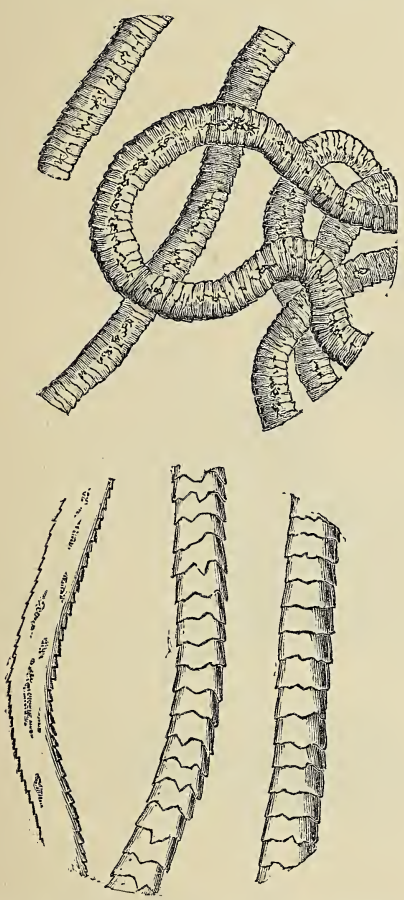


Fig. 51.—Fibres of Wool, greatly magnified.

The peculiar felting properties of wool cause many modifications in its treatment, and important special applications in its manufacture which neither cotton, flax, nor silk are capable of.

Before the felting process is commenced, the oil employed in the earlier stages of the manufacture, to assist the working of the wool, requires to be removed; and this removal is effected by a kind of scouring, the cloth being moistened with soap and water, and beaten with wooden mallets in a kind of trough. Next ensues the *fulling*, *felting*, or *milling*, that process which illustrates more than any other the remarkable qualities of wool. The fact itself, and the various attempts at explaining it, are almost equally curious. When woollen fibres, especially those of the *short*-wool fleeces, are beaten, pressed, or rubbed together, they cling so intimately one to another as to form a tolerably firm layer or group. Such is the case in forming the "nap" of woollen cloth, in forming the body as well as the covering of a beaver hat, and in various other instances. There is an odd legend current respecting the origin of felting, to the following effect:—St. Clement, fourth bishop of Rome, being obliged to fly from persecution, found his feet to be so blistered by long-continued travel that he was induced to put a little wool between his sandals and the soles of his feet. On continuing his journey, the warmth, moisture, motion, and pressure of the feet, caused the wool to clot and mat together into a coherent mass; and this fact led him to think that such felted wool might be a useful material for manufacturers. But unfortunately for the credit of this legend, the felting of wool has been known from very early ages by the nomadic tribes of central Asia, who employ the wool of their sheep for tents and clothing.

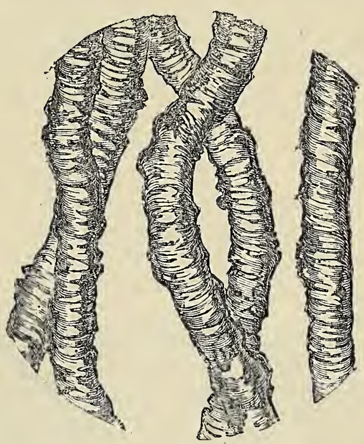


Fig. 52.—Fibres of Wool, greatly magnified.

In modern times, when the "reasons for things" are more sedulously inquired into, the cause of the felting property has engaged a good deal of attention. Dr. Young suggested that "the reason of the contraction of the cloth in felting is probably this: that all the fibres are bent by the operation of the fulling-hammers,

but not equally; and those that have been the most bent are prevented, by their adhesion to the neighbouring fibres, from returning to their original length." A more correct mode of judging arose from the observation of the fact that if a few filaments of wool be drawn between the finger and thumb, in a direction from the root to the tip, the surface of the fibres seems smooth and regular; but if the direction be reversed, there appears to be some slight roughness or interruption to the movement. Mr. Bakewell offered a suggestion that this roughness may be a kind of tremulous motion, "caused by minute vibration, more easily excited in one direction than another, owing to the peculiar arrangement of the particles." It was not, however, till the microscope was applied to the examination of the fibres, that the true cause of felting was discovered. Dr. Ure, who devoted a good deal of attention to this mode of examination, and who recommended that the fibres should be immersed in Canada balsam while under examination, says:—"The filaments of wool so seen in a powerful achromatic microscope have somewhat of the appearance of a snake, with the edges of its scales turned out a little from the surface, so as to make the profile line of the sides look like a fine saw, with the teeth sloping in the direction from the roots to the points. Each fibre of wool seems to consist of serrated rings imbricated over each other, like the joints of equisetum (mare's tail). The teeth differ in size and prominence in different wools, as well as the annular spaces between them—the latter being in general from $\frac{1}{2000}$ to $\frac{1}{3000}$ of an inch, while the diameter of the filament itself may vary from $\frac{1}{1000}$ to $\frac{1}{1400}$. The transverse lines resemble a little the wrinkles of an earthworm, but they are less regular in their course. Were a number of thimbles with uneven edges to be inserted in each other, a cylinder would result, not dissimilar in outline from a filament of Spanish Merino wool—the fleece in which this texture is best developed. In the finest Saxony wool, the articulated appearance is also prominent, and of course the serrated profile of the edges. They are likewise well marked in Mr. M'Arthur's best long combing-wool. In the Leicestershire long staple the serrations are very minute, and the cross-markings indistinct." In Figs. 51, 52, several varieties of wool-fibre are shown, as seen in a powerful microscope, and exhibiting different degrees of the tooth-like serrations at the surface. It is observable that the long wool used for worsted is less decidedly marked than that fitted for woollen cloth. The fleece of the Merino sheep (Fig. 53) has fibres well fitted for this latter object; and it is for this reason that sheep of this breed are so much valued for this department of industry.

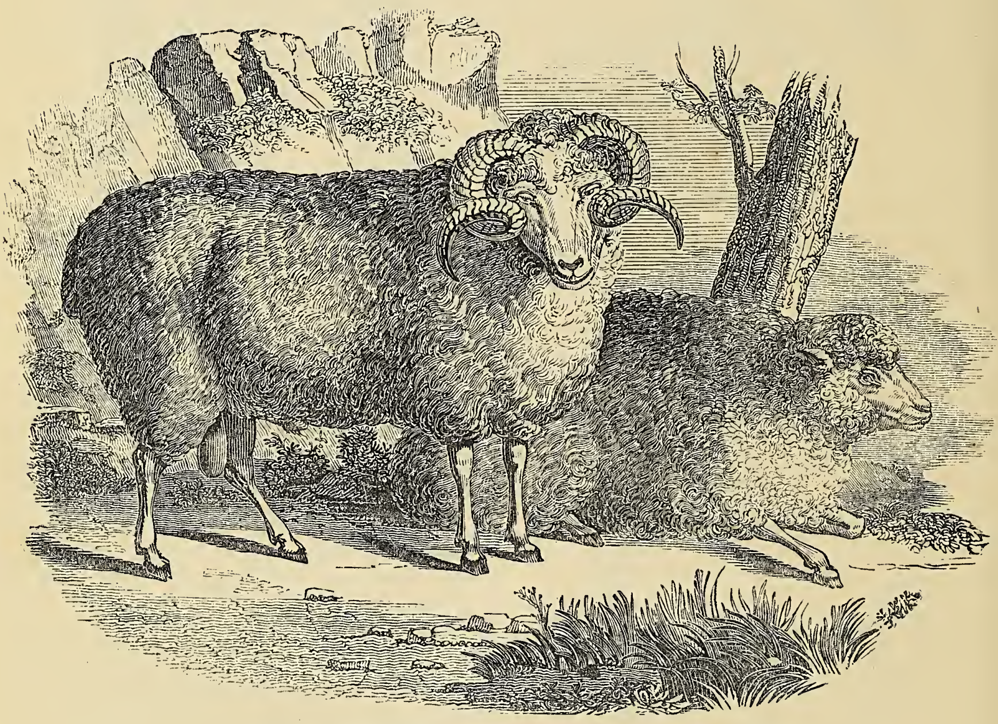


Fig. 53.—Merino or Short-wool Fleece, for Woollens.

It is, then, owing to minute projections on the surface of the fibres, that wool acquires the property of felting; and we may now see how the operation is performed in the manufacture. The "fulling-stocks" employed are hollow machines, in which a ponderous oaken hammer or "stock" vibrates up and down, giving forcible blows to anything that may be in the machine. The woven cloth is partially opened and sprinkled with liquid soap from a vessel held in the hand. It is folded up into a pile, placed in the machine, and there beaten by the hammers. The finest cloth is beaten for nearly two or even three entire days; being taken out four or five times, to have a renewed supply of liquid soap. During this long-continued action, the fibres, being at every blow strongly impelled together, and driven into the closest possible contact, hook into each other by the serrations at their surfaces, until they become inextricably entangled: the fine fibres of one thread of yarn lock into those of another, and the result is, that the distinction between warp and weft becomes hardly perceptible. In the modern woollen factories the fulling-stocks are worked by a steam-engine; but at an earlier period of the manufacture water-wheels were employed for this purpose. The rivers flowing through many of the valleys in the West Riding of Yorkshire used to turn many a water-wheel so appropriated. Dyer, in his poem of "The Fleece," alludes to the industrial features of the district in his time:—

> "Next from the slacken'd beam the woof unroll'd,
> Near some clear sliding river, Aire or Stroud,*
> Is by the noisy fulling mill receiv'd;
> Where tumbling waters turn enormous wheels,
> And hammers, rising and descending, learn
> To imitate the industry of man.
> Oft the wet web is steep'd, and often raised,
> Fast dripping, to the river's grassy bank;
> And sinewy arms of men with full-strain'd strength
> Wring out the latent water."

To some extent we have anticipated the process of weaving wool into cloth; but this has been necessary, because, as already explained, wool has certain peculiarities that other fibrous substances do not possess. When the cloth has by these means been properly felted or "fulled," it is stretched out and hung up to dry. We have here an illustration of the changes which the manufacture has undergone within the last few years. Some time back almost every woollen-cloth manufactory had a "tenter-field:" this was a large open space of ground, containing rows of poles and rails studded with tenter-hooks, on which the cloth was stretched while drying (see *ante*, page 58). Formerly, in and near all manufacturing towns, there were "tenter-fields," with the cloth hanging up in them to dry: but this method soon gave way to drying in steam-heated rooms; and some manufacturers have turned their tenter-fields into gardens for their workpeople, but more frequently into an extension of the factory, since land has become so valuable in the manufacturing districts.

* These rivers are respectively the localities in Yorkshire and the West of England where the woollen manufactures have been so long carried on.

The cloth becomes greatly thickened by the process of fulling; while its length and breadth are diminished nearly one-half. Its surface is rough and unseemly, and has to undergo a remarkable process before completion. It is first "raised;" that is, the mass of the cloth is raked up by a brush, made either of wires or of teazle-heads, and used either by hand or by machine. The use of the teazle (Fig. 54) for this purpose is somewhat remarkable, since it has never yet been superseded by mechanical arrangements.

We extract from the Crystal Palace Catalogue of the Woollen Exhibition of 1881, the following description of the teazle as now in use. The teazles were exhibited by Messrs. North, William, and Son, English and foreign growers,

Fig. 54.—Teazle (*dipsacus fullonum*) used for "raising" Cloth.

of Woodhouse-lane, Leeds, and they were awarded the prize medal at the Exhibition of Arts and Manufactures, held at Leeds in 1875, for excellence of quality.

"Teazles are used for the purpose of raising blankets, flannels, and the smooth and high-faced cloths, etc., and, though mechanical appliances of wire have been frequently tried for the purpose as experiments, they fail to compete with the natural product for effectually raising the nap without injuring the fibre of the material, the soft pithy core in the centre of the

barrel forming an elastic spring, which allows the hooks or points to give way and come into position again as required, in a manner which cannot be imitated by science. Yorkshire produces the best teazles in the world, when there is a fair crop; those second in value are cultivated in the West of England, and next to these come those grown in the Normandy districts. Lower qualities are found in the South of France, Germany, Austria, etc. The crop takes about eighteen months to grow. In England teazles are sold by the pack of 13,500 heads, and the price varies greatly, according to the quality and size. With respect to *size*, they are divided into kings, seconds, and small, and are tied up in staves of 300 or 500 each when sold loose, or by the load. When packed in assorted cases, the stems are cut to a uniform length of about 3 inches, and the kings are marked ◊; seconds are subdivided into the sizes called G (ranging from $2\frac{1}{2}$ inches to three inches); O (2 inches to $2\frac{1}{2}$ inches); and P ($1\frac{3}{4}$ inches to 2 inches) respectively; whilst the small are classed as T ($1\frac{1}{2}$ inches to $1\frac{3}{4}$ inches), and BT, or buttons (all below $1\frac{1}{2}$ inches in length). The cases weigh from 3 cwt. to $3\frac{1}{2}$ cwt. gross, measuring about 58 cubic feet, and contain, according to the dimensions of the teazles, 14,000 to 100,000 heads. Occasionally these various classifications are further divided into long and short G's ($2\frac{3}{4}$ inches to 3 inches and $2\frac{1}{2}$ inches to $2\frac{3}{4}$ inches); long and short O's ($2\frac{1}{4}$ inches to $2\frac{1}{2}$ inches and 2 inches to $2\frac{1}{4}$ inches), etc."

The object of using these teazles is to draw out the ends of the wool from the woven cloth, so as to bring a pile or nap upon the surface, free from twistings and knots, and also to comb off the loose fibres of wool. The teazle is enabled to effect this, because the head is composed of incorporated flowers, separated by a long rigid filament, the terminating point of which is furnished with a fine hook. These hooks comb out and loosen the woolly fibres; and the peculiarity of the service which they render is this—that if any of the hooks encounter a knot or a resistance in the cloth, they will break without injuring the cloth itself. This is the great point in which teazles have been found preferable to any arrangements of wire teeth; since the latter tear the cloth rather than give way to obstructions by breaking. But there are great inducements to the invention of some substitute, for the use of the teazles is rather costly.

When the loose and delicate filaments of wool have been thus worked up to a rough state, they are cut or sheared to a surface beautifully level and even, by a process which has undergone many modifications. In former times this was done by hand-shears. The cloth was stretched out over a stuffed table, and the workmen proceeded to clip the points of the fibres from end to end, and from side to side, by laying the shears flat down on the cloth and making cuts with them in regular succession. This was an operation requiring very great care and skill, and the workmen earned high wages. At a later period an improvement was effected, whereby the shears were worked by machinery instead of by hand labour. Subsequently other machines were invented to effect the result in various ways, but all acting on a principle partaking somewhat of that of shears or scissors. The details of this will be more fully dealt with in a subsequent page.

The finer kinds of cloth are raised and sheared, until the nap has acquired a beautiful degree of smoothness and regularity. Many minor processes are also about this time employed, especially for the better qualities of cloth. For instance: the cloth is "boiled," to impart to it a certain lustre; it is "burled," or "picked," to remove knots and imperfections; it is "inked" (if black or blue cloth) by women, who carefully examine the cloth in every part, and put a spot of ink on any white or light-coloured fibres that may present themselves; it is "pressed" between hot iron plates and smooth mill-boards; it is "steamed," and then brushed by passing the cloth over cylinders covered either with brushes or a kind of plush. The coarser varieties of cloth do not require so many finishing processes.

Before quitting that part of our subject relating to the finishing of woollen cloth, it may be well to notice a method which the Romans adopted in scouring or cleaning their woollen goods. It was mentioned in an earlier part of the present chapter that the preparation of such cloth formed part of the industrial arts of the Romans; and there are some paintings at Pompeii which throw a little light on the arrangements connected with this subject. In the volumes relating to "Pompeii" it is said that the art of fulling and scouring cloth, owing to the difference between ancient and modern habits, "was of much greater importance formerly than it now is. Wool was almost the only material used for dresses in the earlier times of Rome; silk being unknown till a late period, and linen garments being very little used. Woollen dresses, however, especially in the hot climate of Italy, must often have required a thorough purification; and on the manner in which this was done, of course, their beauty very much depended: and since the toga, the chief article of Roman costume, was woven in one piece, and was, of course, expensive, to make it look and wear as well as possible, was very necessary to persons of small fortune. The method pursued has been described by Pliny and others; and is well illustrated in some paintings found upon the walls of a building, which evidently was a *fullonica*, or scouring-house."

Fig. 55 is a copy from one of the paintings here alluded to; and from the description given it appears that the process of scouring commenced by washing the cloth in water containing fullers' earth, or some other kind of detergent clay. This was done in vats, where the cloth was trodden and well worked by the feet of the fullers. In the painting there are four persons represented thus employed; the dress, consisting of two tunics, being tucked up so as to leave the legs bare. Three of the men seem to have finished their work, and to be wringing out the

cloth; while the other, his hands resting on the wall on each side, is jumping and stamping on the cloth in the vat. When dry, the cloth was brushed and carded to raise the nap, at first with metal cards, and afterwards with thistles. The cloth was then fumigated with sulphur, and bleached in the sun by throwing water repeatedly on it, while spread out on gratings. In another of the paintings a workman is represented as brushing or carding a tunic suspended over a rope. Another man carries a frame and pot, intended probably for fumigation and bleaching: the pot probably contained hot charcoal and sulphur, and was placed under or within the frame; while the cloth was spread over the exterior of the frame, so as to be fully exposed to the action of the vapour rising from the burning materials. On the left is a female examining the work which a younger girl has done upon a piece of yellow cloth. A golden net upon her head, a necklace and bracelets, denote a person of some consequence; and she is supposed to have been either the mistress of the establishment or a customer come to examine some work executed for her.

Another of the pictures at the *fullonica* represented a clothes-press very much resembling presses still in use. This was probably intended to press and smooth the cloth after it had been scoured and bleached.

The wool employed for these purposes differs both in the length and the quality of the fibres from that used in the manufactures just noticed. But in many departments of the manufacture the processes are very much the same. Thus the spinning-wheels of the domestic fire-side in country districts used to be pretty much the same, whether flax, cotton, wool, or worsted were the object of attention. The allusions to this homely mode of spinning by our poets and early writers are numerous. Shakespeare, in "Twelfth Night," makes the Duke say :—

> "Come, the song we had last night,
> Mark it, Cesario; it is old and plain;
> The spinsters and the knitters in the sun,
> And the free maids that weave their thread with bones,
> Do use to chant it."

As compared with the wool employed for woollen cloth, the long or combing-wool is characterised by strength and transparency, but is deficient in the power of felting. There are two varieties—the "long-combing" and the "short-combing"—both partaking of the class of worsteds, but in a different degree; the long-combing wool has an average length of about eight inches, and is used in the manufacture of hard yarn, and for other purposes in which length and firmness of fibre are requisite; whereas the "short-combing wool" is shorter, finer, and more disposed to felt, and is used for hosiery goods and for stuffs of soft texture. Fig. 56 shows the kind of sheep from which combing-wool is produced.

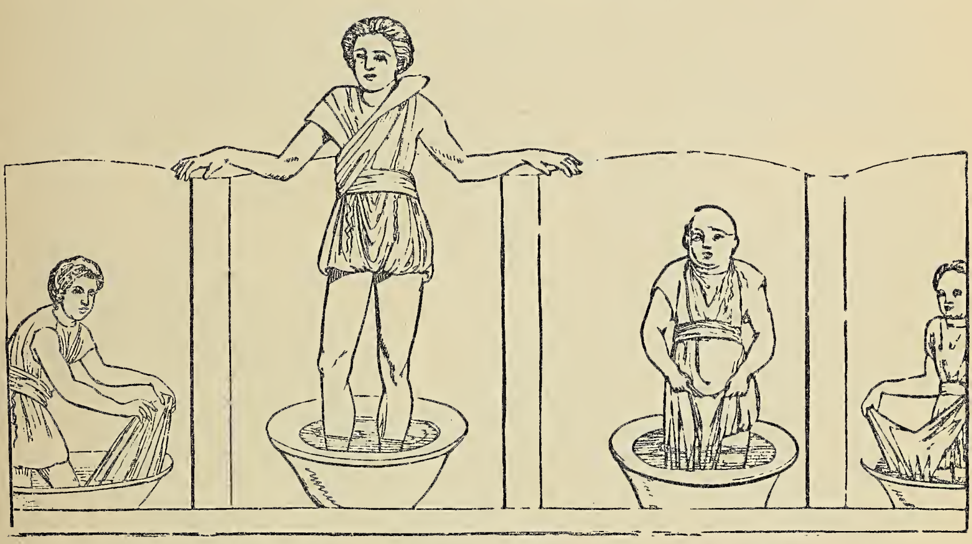


Fig. 55.—Woollen-cloth Fullers and Scourers. (From a Painting found at Pompeii.)

The processes which this wool undergoes in its transformation to worsted yarn, so far from being calculated to make the individual fibres lock into each other by the little roughnesses or teeth on the surface, are intended to facilitate the production of a fine, even, and smoothly-spun thread; and, indeed, the felting power of the wool is purposely injured or lessened in the earlier processes.

In the first place the wool is well washed from the adherent grease which it derives from the animal; this is done by working the wool in large vessels containing soap and water, and afterwards pressing out the water by drawing the wool between rollers or cylinders. The wool is then spread out on the floor of a heated room, to be

speedily dried. Then commence the processes of disentanglement, in which machines are used suited to accord with the kind of wool and the purposes to which it is to be applied, One of these machines is called a "plucker," and consists of a pair of spiked rollers connected with an endless apron or belt on which the wool is placed : this is one of the many forms of arrangement in which spikes or teeth help to smooth out and regulate the fibres. The first opening of the fibres being thus effected, they are either "carded" or "combed;" the former being a machine-process for the coarser wools, and the latter a hand-process for the finer. In hand-combing the workman uses a pair of comb-like instruments (Fig. 57). In a block or head are fixed a number of well-tempered, finely-pointed steel teeth, ranged in three rows differing somewhat in length. In order to facilitate the process, the combs are made hot: this is effected by placing the teeth into a small space left between two plates of a stove. The combs being heated, one of them is fixed in a post with the teeth uppermost; the wool is laid on the teeth ; and the other comb combs it out. A homely but sufficient illustration of the process has been thus given :—" If we consider the full comb as the human head, disgraced by a quantity of neglected, long, and dishevelled hair, which we reduce to its elegant order, we shall have a very just idea of the operation and use of this instrument in the worsted manufacture. The very name shows its origin, application, and use." The combing is also for some purposes effected by machines.

Fig. 56.—Long-woolled or Leicestershire Fleece, for Worsted.

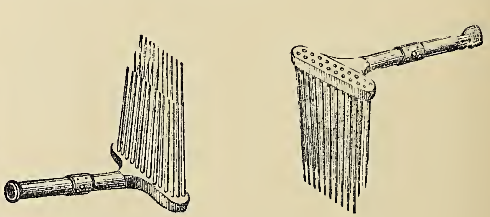


Fig. 57.—Hand-combs for Long Wool.

In all those varieties of the manufacture which require the wool to be carded, the processes bear considerable resemblance to the carding of cotton. The wool is first placed near a revolving cylinder called a *teazer*, whose external surface is studded with bent hooks; and these hooks, catching hold of the locks of wool, disentangle and open them, separating them fibre from fibre, and preparing them for the "cards." These cards are wires, much finer than the hooks of the teazer, disposed around the exterior of a long series of cylinders; the wool is caught from one cylinder to another twenty or thirty times in succession, whereby all its fibres become arranged very nearly in a parallel layer; and after leaving the last cylinder, it assumes

the form of a delicate tender riband or "sliver." By this mode of dealing with the material, a great change has been wrought in the manufactured goods of Bradford, Halifax, and other towns where the combing-wools are employed. The *noil* of long-fleece wool and a great deal of skin-wool (that taken from the animal after being killed), which used to be employed only in blanket and coarse woollen work, can now be worked up into coarse worsted yarn; and the price has been so lessened by the change, that nearly all coarse worsted yarn is now produced by carding. The improvement has led to vast increase in the consumption of wool within the last few years; for any fibres, however short, may be carded; whereas none under a length of six inches can be hand-combed; the result of which is that all the kinds of wool now reared in England can be spun into yarn of one kind or other.

From an inspection of the following woodcuts (Figs. 59 to 61), and on comparison of them with others which have been before given in connection with the cotton manufacture, it will be seen that the processes of "drawing," "roving," and "spinning" the wool into worsted yarn, are very similar to the like-named processes in other manufactures. In the first place the wool, supposing it to have been "combed" by hand, is laid upon an endless band, and carried between drawing rollers, by which it is elongated, ranged parallel, and conveyed in the form of a delicate riband into a cylindrical can. A repeated series of similar elongations and rearrangements brings it to the state of a "roving," and then to that of yarn, fit to be used either by the weaver of stuffs and similar goods, or to be made into hosiery at the stocking-frame.

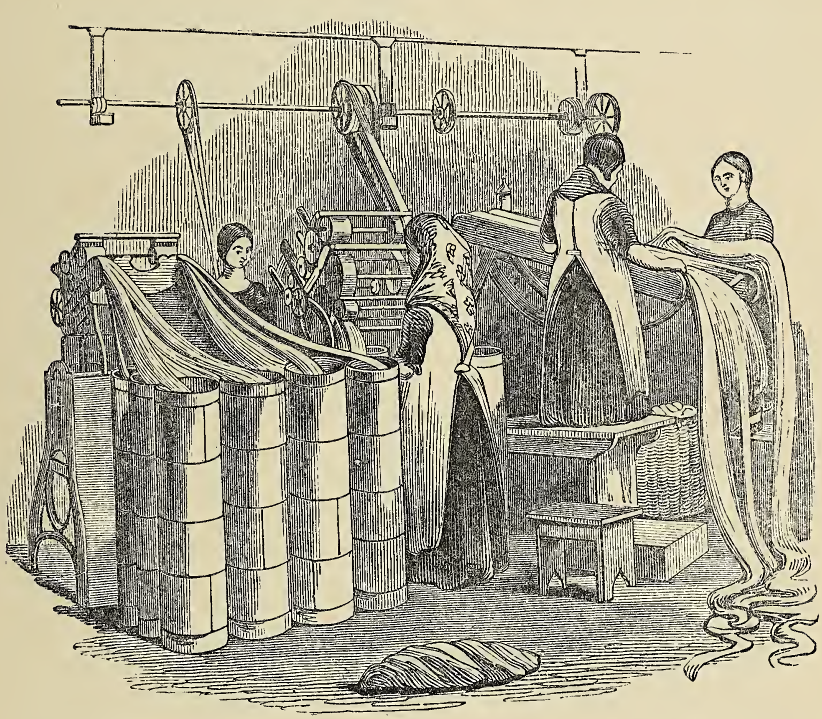


Fig. 58.—Drawing Worsted into Slivers.

Weaving.

In the preceding pages we have traced the various steps by which the raw material of cotton, flax, silk, and wool, is changed into the form of yarn, so as to fit it for the purposes of the weaver. Before describing the art of weaving, we may briefly notice that sewing cottons, silk thread, linen, and woollen threads simply consist of the single yarn doubled, or in some cases, for the sake of strength, made sixfold for the use of the sempstress, the knitter, the tailor, shoe-maker, and others, and that the process by which this is accomplished in all respects resembles that of spinning in its last stage. According to the purpose for which cotton thread is employed it is twisted hard, as in sewing cottons, and loosely as in "mendings." The same remarks apply to many kinds of wool for knitting, as "Berlin," "Scotch," etc. Silk twist is largely and chiefly used by the tailor, and linen thread by the bootmaker, the carpet manufacturer, etc.

If a piece of woven material, of any of the common kinds, be picked to pieces or closely examined, it will be seen that there are two sets

of threads, crossing each other at right angles; and that the strength and firmness which the cloth possesses results from the interlocking of these threads, those which pass in one direction being made to go alternately over and under those extending in the other direction. It will further be observed, that the appearance of the cloth suffers a good deal of diversity according to the order or system in which the interlocking occurs. If a piece of linen, or of calico, or of plain silk, or of plain merino be examined, it will be found that the cross-threads go over a long or warp thread, then under the next one, then over the third, under the fourth, and so on, changing at every thread individually. But in the more figured or fancy goods, this alternation is by no means so regular. In *twills*, for example, whatever be the material (for the word twill has relation to the mode of weaving, and not to the material of the cloth) the weft or cross-thread passes over one warp or long thread, under two, three, or more, over one, under two or more, and so on; always passing under more threads than it passes over. Sometimes the number of threads thus passed at once is as large as six, eight, or ten. One consequence of this mode of intersection is that there is a diagonal ribbed appearance on the face or upper surface of twilled goods, while the back or lower surface exhibits a kind of loose texture or flushing. We may give something like a rude explanation of this by means of Fig. 62, where we are supposed to see a piece of twilled cloth *edgewise:* the round black spots represent sections of the warp-threads; while the white line represents a weft-thread, passing first under or over four warp threads, and then under or over one. In plain twilled goods the weft usually passes under more threads than it passes over; but here it will be seen that the system alternates, the groups of four being sometimes under and sometimes over. One result of this alternation is to give figured patterns to the cloth, such as are seen in dimity or diaper, while the more simple alternation gives rise to the kerseymere kind of texture. Other kinds, such as *gauze*, have the warp-threads twisted around each other after every intersection of the weft. In Fig. 63, for instance, the black lines may represent the warp threads twisted round each other, while the white lines may represent the weft-threads passing between and among them.

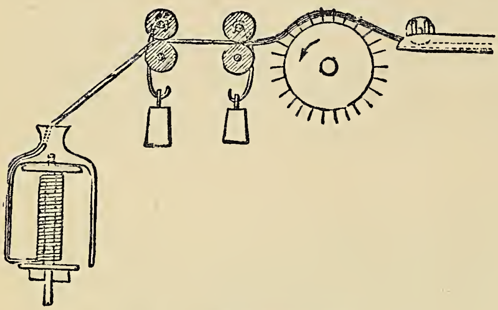


Fig. 59.—Worsted-roving.

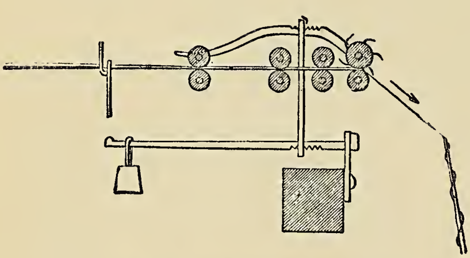


Fig. 60.—Worsted Throstle.

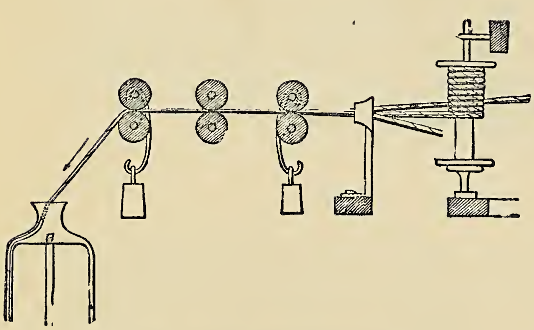


Fig. 61.—Worsted-spinning.

Fig. 62.—Diaper and Kerseymere.

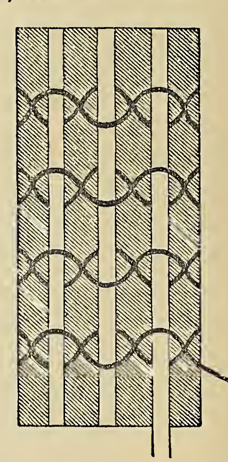


Fig. 63.—Gauze.

The origin of the art of weaving is lost in obscurity. A perusal of c. xxxv. Exodus gives the impression that it had attained great progress some thousand years ago. Sir J. G.

Wilkinson found, among the monuments of Egypt, representations of the looms used by that remarkable people in early times. He states, on the one hand, that these looms appear to have been exceedingly rude in construction; while, on the other hand, he notices the fact that the Egyptians, from a remote æra, "were celebrated for their manufacture of linen and other cloths, and the produce of their looms was exported to, and eagerly purchased by, foreign nations: the fine linen and embroidered work, the yarn and woollen stuffs, of the upper and lower country, are frequently mentioned, and were highly esteemed." It might seem contradictory to speak of the rudeness of the looms, and at the same time of the excellence of the produce; but the example of the Hindoos shows us that delicacy of touch may go far to compensate for deficiency of mechanical aid. The writer here quoted, speaking of the proofs that figure-weaving was known to the early Egyptians, says:—"Some portions of woollen-work have been found at Thebes, which presented the appearance of a carpet: and a small rug was lately brought to England, and is now in the possession of Mr. Hay. This rug is eleven inches long by nine broad. It is made like many carpets of the present day, with woollen threads on linen string. In the centre is the figure of a boy in white, with a goose; above it the hieroglyphic of a 'child' upon a green ground; around which is a border composed of red and blue lines; the remainder is a ground of yellow, with four white figures above and below, and one on each side, with blue outlines and red ornaments: and the outer border is made up of red, white, and blue lines, with a fancy device projecting from it with a triangular summit which extends entirely round the edge of the carpet. Its date is uncertain; but from the child, the combination of the colours, and the arrangement of the border, I am inclined to think it really Egyptian. I have also been informed by Lord Prudhoe that in the Turin Museum he met with some specimens of worsted worked upon linen, in which the linen threads of the weft had been picked out and the coloured worsted sewed in the warp."

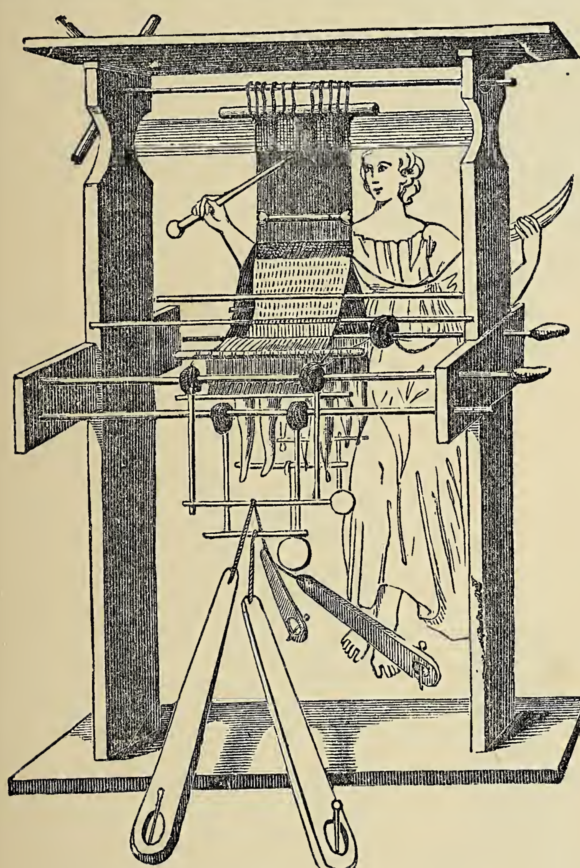


Fig. 64.—Ancient Loom. (From Montfauçon.)

There was for a long time a good deal of doubt concerning the material from which the mummy-cloths of Egypt were made; but it is now known that they were made of linen or flaxen cloth. Mr. Thomson, of Clitheroe, one of the most scientific among our manufacturers, examined many specimens of mummy-cloth with a view of determining how it was woven. In one specimen he found that the texture was close and firm, yet elastic; the yarn, both of warp and of weft, was remarkably even, and well spun; the weft was single, while the warp-yarn consisted of two threads doubled together; and it was observable in that, as well as in other specimens, that the number of threads to an inch in the warp uniformly exceeded that in the weft—a difference not usually found in European woven goods. In more specimens, brought to England by Salt and Belzoni, Mr. Thomson found that the "selvages" were well made; that striped goods, similar to modern ginghams, were often made by the Egyptians; and that indigo was used as one of the dyes. From some of the pictures found at Thebes, and other parts of Lower Egypt, it appears that the loom was sometimes horizontal, but generally vertical, and that the shuttle was almost half a yard in length.

The looms used by the Greeks and Romans seem to have had the warp-threads ranged vertically, like those in Fig. 64, which is copied from a curious old engraving in Montfauçon; and the methods appear to have been known whereby the varieties of weaving known by us as "checks" and "stripes" could be produced.

When we transfer our attention to Oriental countries, as presented to our notice at the present day, we find that the looms have the warp-

threads ranged horizontally, as with us, but that the subsidiary arrangements are much more primitive and rude.

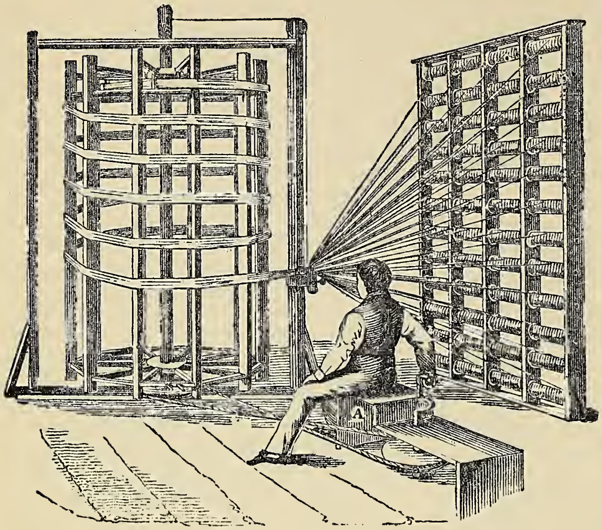


Fig. 65.—Warping Yarn for Muslin.

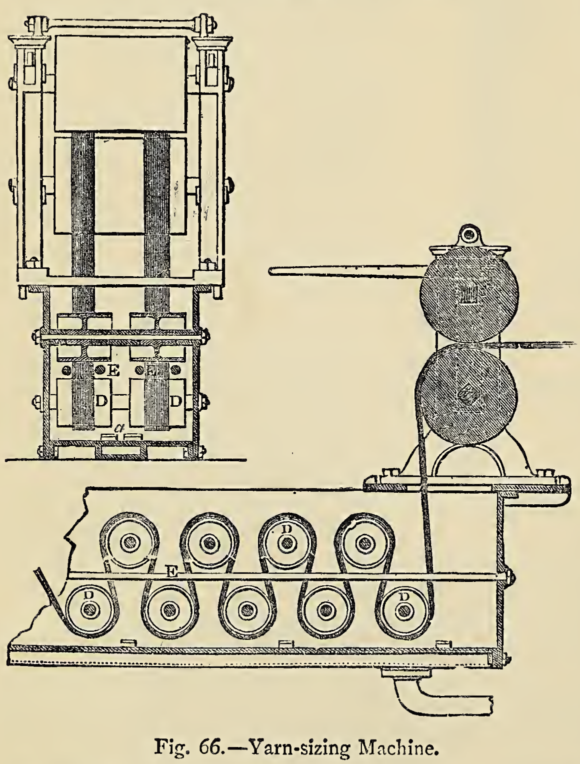


Fig. 66.—Yarn-sizing Machine.

For reasons that are obvious, certain processes must be gone through to render the yarn, especially of cotton, fit for the purposes of the weaver. One of these is the process of *warping*, the nature and object of which may be very readily understood. As the hanks of spun material, whether cotton or any other, are wrapped up closely, the yarn requires to be stretched out and laid parallel before it is fitted to act as warp for the woven cloth; and this process of arranging it is called warping. There have been, at different periods in the history of weaving, four different modes of performing this process: by the aid of the warping-field, the warping-frame, the warping-mill, and the warping-machine. In the first and most ancient of these, the warp is removed from the bobbins by hand, and stretched out in an open field. Dyer, in his poem of the "Fleece," mentions this mode of warping as if it were customarily practised in his day in England, for he describes the warper occupied as he

> "strains the warp
> Along the garden walk, or highway side,
> Smoothing each thread."

The *warping-frame* is a large wooden frame, fixed upright either against the wall or on a stand. The sides of the frame are pierced with holes to receive wooden pins, which project sufficiently to receive a large number of yarns. The warper arranges in an adjoining piece of apparatus as many bobbins of yarn as there are to be threads in his warp. He ties the ends of all the threads together, and walks to and fro before the frame, passing the clue or group of yarns over all the pegs in succession. The bobbins unwind as he proceeds; and the yarn slips through his hand as he walks along. When all is completed, he takes the yarns off the pegs; and has then grouped into a long, loose roll, as many threads as will form his warp. Some of the ancient representations connected with the clothing arts, illustrate a small kind of warping-frame, with indications seeming to show that, in weaving, the warp was arranged vertical, instead of horizontal, as with us.

Another and more efficient mode of warping is by the aid of the *warping-mill,* of which one form is seen in Fig. 65. There are here two frames or machines, and a winding apparatus placed near them. The bobbins are placed in an upright frame, in such a way that the yarn can readily unwind from them. The yarns from all the bobbins, collected together in a group at one spot, are attached to the frame whereon they are to be wound. The warper, sitting on a stool, sets a kind of hollow vertical frame in revolution by means of a handle and rope, and by so doing

Samuel Crompton

causes all the yarns to be unwound from the bobbins, and re-wound on the vertical reel. By a peculiar arrangement of the apparatus, the clew of yarns is wound spirally round the reel, from which it is at length removed in a continuous group.

In the *warping-machine*, connected with power-loom weaving, the warping and other processes are conducted pretty much at the same time. The bobbins containing the yarn are ranged with their axes horizontal and parallel. The yarns are drawn from the bobbins, made to pass under some rollers and over others, and are at length brought into a parallel layer, with a comb or grating of fine wires so employed as to separate the yarns in an equidistant manner. After having so passed, the

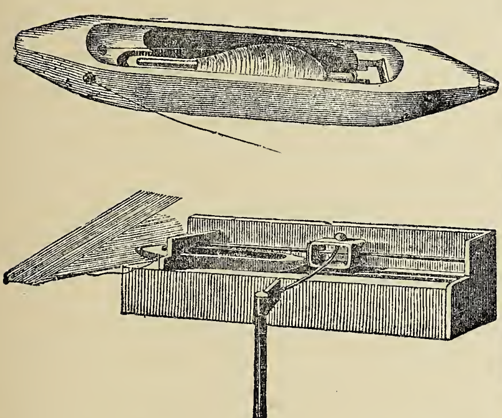


Fig. 67.—Shuttle of Power-loom.

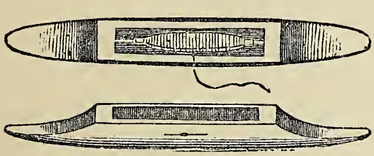


Fig. 68.—Shuttle used by the Cingalese.

yarns are made to coil round a roller or beam, and are in that state removed from the machine. But constant improvements are made in the machinery employed for this purpose.

So far, then, the object has been to collect together as many threads as will form the warp of the cloth, but without arranging them in the loom where they are to be woven. But cotton goods require a certain kind of "dressing" or "sizing" before being woven, in order to give the warp-threads the proper degree of stiffness. In hand-loom weaving the warp-yarns are dressed as the weaver proceeds: he suspends his operation from time to time, clears away knots and burs from his warp by a kind of comb, lays on a warm coating of paste or size with a brush, and dries the paste by a current of air excited by a large fan. In the power-weaving method, however, eight rollers, containing yarn which has been warped, are so placed that the yarn from them may, when unwinding, pass between two rollers before being transferred to a larger beam; and as the lowermost of these two rollers revolves in a trough containing paste, the yarns become coated with paste by this means. They next pass over and under brushes, by which the paste is rubbed into the fibres of the yarn; and after this they pass over hollow cylinders heated by steam, by which they are quickly dried. Sometimes, for particular purposes, the yarns are sized, instead of dressed, by means of the machine sketched in Fig. 66, of which the upper or left-hand portion represents the section in

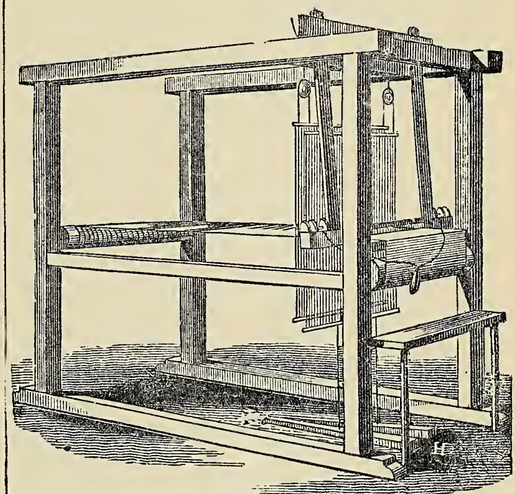


Fig. 69.—The Hand-loom.

a is the roller on which the warp threads are wound; *b*, the warp-threads passing through the heddles, *c c*; *d* is the shuttle, now shown out of its place; *e* is the frame working the reed, which is pressed against the last weft-thread thrown in by the shuttle, and is worked by hand. The treadles working the heddles are seen beneath.

one direction, and the lower or right-hand portion the section at right angles to the former. There is a large trough filled with melted size, through which the warp is made to pass. There are several rollers, D, immersed in the size, and several more above them; and the yarn, E, travels over all of them, being alternately wetted and pressed.

The "beaming," the "drawing in," and the "winding," are other processes intended to prepare the yarn for the purposes of the weaver. In beaming, the yarns which had previously been warped are coiled round a large beam belonging to the weaving-loom, and are ranged as parallel and even as possible. In "drawing in," parts of the warp are loosened or unwound from the

beam, and women prepare it for the reception of loops or eyes essential to the working of the loom. In "winding," as applied to the weft-threads and not to the warp, the yarn is unwound from the bobbins, and re-wound upon a little pin or axis running through the shuttle. This shuttle is a little boat-like instrument (Fig. 67, and upper part of 67) having a recess in which this pin or axis revolves; and has also a small hole so adjusted that the yarn may unwind from the pin, and leave the shuttle as fast as it is wanted for the weaving process.

It is somewhat remarkable that the Cingalese have perhaps for ages past used a similar kind of shuttle, a representation of which is given in Fig. 68.

Hand-loom Weaving.—A common hand-loom (such as sketched in Fig. 69) consists of several parts, some of which are required to keep the warp-threads extended to their proper length; some to spread them out to the proper width; some to separate them into two parcels, according as the weft-thread is to pass over or under them; some to make these two parcels alternate in their movement up and down; some to drive up every weft-thread close to the one before introduced, before throwing in another; some to wind up the woven cloth as fast as it is made, and to unwind more warp from another part of the machine.

At the further part of the machine is a cylindrical beam or roller, fixed by pivots at each end so as to revolve; this is the "warp-beam," on which the yarn forming the warp is wound. The warp from this beam is capable of being drawn out into a horizontal layer, stretched across to the foremost end of the loom. Suspended vertically from about the middle of the machine are a series of strings; there are two sets or leaves of "treadles," each leaf consisting of a number of strings ranged vertically, attached at the bottom to two treadles, on which the weaver places his feet, and at the top to a cross-bar. Each string has, near its middle, a loop or eye, through which the warp-yarns are drawn. The yarns of one parcel, consisting of every alternate yarn throughout the layer or series, pass through the loops in one leaf of treadles: while those of the other parcel pass through the loops of the second treadle; and as these two vertical treadles, or groups of strings, are so connected that one sinks when the other rises, and *vice versâ*, the warp-threads are necessarily separated into two sets, each set forming a layer alternating above and below the other. There is thus an opening formed between the two sets of warp-threads, and into this opening, called the "shed," the shuttle is thrown containing the thread which is to constitute the weft, or "cross-thread."

In the lower part of Fig. 67, for example, there is a small portion of this divided warp shown, with the point of the shuttle just about to enter it.

Such, then, being the chief component parts of the loom, the manner in which they are brought to bear on the object in view is as follows:—The weaver sits at the front end of the loom, and presses down with his foot one of the two treadles; by which action one of the two halves or groups of the warp is depressed, thereby forming the shed. Into this shed he throws the shuttle with one hand (say, the right) with sufficient force to drive it completely through the shed, and out at the other side. He catches the shuttle in his left hand, and with his right grasps the "batten," which is a kind of frame, carrying at its lower edge a sort of comb, having as many teeth as there are threads in the warp: this batten, when pulled towards the weaver, drives up the thread of weft close to those previously thrown. All the operations connected with the introduction of one thread of weft are now completed; and the weaver proceeds to throw in another thread, but reversing the action of his hands and feet. He presses down the treadle which had before been raised, and raises that which had before been depressed; and the groups of warp-threads becoming thus reversed in position, he throws the shuttle with his left hand towards his right, instead of from the right to the left; he drives up the weft-thread, by means of the batten, with his right hand, instead of his left, as before. This completes the second stage; and he then commences with the third stage similarly to the first; then the fourth similarly to the second, and so on. When he has intersected a sufficient number of threads of weft among the warp to make a few inches of cloth, he winds this cloth on the "cloth-beam" in the front of the machine, unwinding at the same time an equivalent length of warp from the "warp-beam" at the back of the machine.

Contrivances have been at different times introduced for facilitating the throwing of the shuttle in weaving. In the commonest modes of proceeding the shuttle is, as we have just described, thrown alternately with both hands; but in the "fly-shuttle" there is a string and a handle so placed that the weaver can work the shuttle both ways with one hand. The shuttle, and the apparatus connected with it, represented in the lower part of Fig. 67, are connected with power-loom weaving, to which we shall presently direct our attention.

There are numberless old engravings extant exhibiting the common hand-loom under a form approaching more or less nearly to that just described. In one, for instance, is a print by Schopfer, published at Frankfort nearly three centuries ago, a Flemish weaver working at his loom. The heddles, the treadles, the batten, the shuttle, the cloth-beam—all are there; and by the side of him appears to be a pan and brush for "dressing" the warp with paste. A woman seems to be bringing him yarn; and there is more yarn in a basket behind him.

Hogarth, who attended with such wonderful minuteness to the accessories which might enable his pictures to tell their own tale, and to work out a history of manners, has not left us in the dark concerning the clothiers' looms of his day. In his series on "Industry and Idleness," there is one in which two such looms are shown. In it we can trace the warp-beam,

the cloth-beam, the treadles, the batten, and the shuttle. On the floor, too, are a reel and a wheel for winding the yarn on the pirn of the spindles. The *moral* illustrated by the two apprentices sitting at the looms (and Hogarth had a deep moral in all his pictures of this class), has been thus pointed out:—"The one, whose open, intelligent countenance at once wins our regard, is intent upon the duties of his occupation; the other, whose vulgar and unintellectual face is indicative of the habitual progress of his character, is fast asleep. The pewter-pot on the loom and the tobacco-pipe by its side show that his drowsiness proceeds from indulgence rather than from fatigue. He is equally indifferent to the noise of the cat who is playing with his shuttle, and to the angry step of his master, who is entering the door with a cane uplifted for his chastisement. The accessories of the scene are few and simple, but they assist the development of its characters. The industrious apprentice has fixed upon the wall some papers which may incite him to persevere in his course of diligence, such as the 'Life of Whittington:' the idler has stuck up a profane ballad of that day, called 'Moll Flanders.' The 'Prentice's Guide' of the one is carefully preserved; that of the other is torn and dirty. The artist, in this first plate of his series, has made the difference of the two characters that he intends to contrast in their conduct and their fortunes perfectly intelligible. He has strikingly availed himself of the general inclination to associate certain qualities of the mind with certain forms of countenance and modes of expression."

Power-loom Weaving.—By referring to page xxxvii. the reader will find that in the early stages of the cotton manufacture great scarcity of yarn existed. Mr. Guest says that a weaver was often under the necessity of trudging three or four miles in a morning, and visiting many spinners before he could collect weft enough to keep his loom going during the rest of the day; and such was the competition which he met with from other persons having a similar errand, that he had frequently to fee and make presents to the spinners to allow him to be the purchaser. In short, the weavers were quite at the mercy of the spinners.

When, however, by the introduction of new machinery and the application of steam as the motive power the production of yarn became unlimited, the weavers were relieved of this difficulty. The next stage was that of the invention of looms driven by steam power, by which the production of calico, etc., could be made equally unlimited, and the outcrop of this was the invention of the *power-loom.* This has completely revolutionised the cotton manufacture. The cost of weaving which in former days amounted to pounds has now been reduced to pence, and consequently dresses which, in printed calico, were formerly of at least thirty shillings to two pounds cost, are now produced, that even the workhouse pauper wears them, so trifling is their cost.

As long ago as the year 1678, ingenuity was directed towards the invention of some machine which should weave cloth simply by the turning of a wheel. M. de Gennes described, in the "Philosophical Transactions" of that year, a machine having this object in view, or rather, he mentioned the fact of such a machine having been devised, but the particular mode of action was not clearly explained. He designated it "a new engine to make linen cloth without the aid of an artificer;" and stated its excellences to be as follows:—"That one water-mill alone will set ten or twelve of these looms at work; that the cloth may be made of what breadth you please, or at least much broader than any which has been hitherto made; that there will be fewer knots in the cloth, since the threads will not break so fast as in other looms, because the shuttle, that breaks the greater part, can never touch them; in short, the work will be carried on quicker and at less expense, since, instead of several workmen, who are required in making up of very large cloths, one boy will serve to tie threads of several looms as fast as they break, and to order the quills in the shuttle." If such important advantages were presented by this machine, it is strange that the new loom itself did not come into use; but as we hear little or nothing more of it, we may conclude that the inventor had somewhat overrated the merits of his own contrivance.

During the last century many projects were started by ingenious mechanicians to shorten in some way or other the process of weaving; and the Museum of the Society of Arts contained at one time a model of one of the machines so contrived by Mr. Austin. But the most notable step in this direction was taken by Dr. Cartwright, who, though not so fortunate as to carry out to his own profit the result of his ingenuity, laid the foundation for a successful prosecution of the method on the part of others. He has left a curious account of the circumstances under which he was led to turn his attention to this matter.

Dr. Cartwright, in a letter to Mr. Bannatyne, thus relates the matter:—"Happening to be at Matlock in the summer of 1784, I fell in company with some gentlemen of Manchester, when the conversation turned on Arkwright's spinning-machinery. One of the company observed that, as soon as Arkwright's patent expired, so many mills would be erected, and so much cotton spun, that hands never could be found to weave it. To this observation I replied, that Arkwright must then set his wits to work to invent a weaving machine or mill. This brought on a conversation on the subject, in which the Manchester gentlemen unanimously agreed that the thing was impracticable; and, in defence of their opinion, they adduced arguments which I certainly was incompetent to answer or even to comprehend, being totally ignorant of the subject, having never seen a person weave. I controverted, however, the impracticability of the thing by remarking that there had lately been exhibited in London an automaton figure which played at chess. 'Now you will not assert, gentlemen,' said I, 'that it

is more difficult to construct a machine that shall weave, than one which shall make all the variety of moves which are required in that complicated game?' Some little time afterwards, a particular circumstance recalling this conversation to my mind, it struck me that, as in plain weaving, according to the conception I then had of the business, there could only be three movements, which were to follow each other in succession, there would be little difficulty in producing and repeating them. Full of these ideas, I immediately employed a carpenter and smith to carry them into effect. As soon as the machine was finished, I got a weaver to put in the warp, which was of such materials as sailcloth is usually made of. To my great delight a piece of cloth, such as it was, was the produce. As I had never before turned my thoughts to anything mechanical, either in theory or in practice, nor had ever seen a loom at work, or knew anything of its construction, you may readily suppose that my first loom was a most rude piece of machinery. The warp was placed perpendicularly, the reed fell with the weight of at least half a hundred-weight, and the springs which threw the shuttle were strong enough to have thrown a Congreve rocket. In short, it required the strength of two powerful men to work the machine at a slow rate, and only for a short time. Conceiving that I had accomplished all that was required, I secured what I thought a valuable property, by a patent 4th April, 1785. I then condescended to see how other people wove; and you will guess my astonishment when I compared their easy modes of operation with mine. Availing myself, however, of what I then saw, I made a loom, in its general principles nearly as they are now made. But it was not till the year 1787 that I completed my invention, when I took out my last weaving patent, August 1st of that year."

Dr. Cartwright, after this, tried to establish a power-loom weaving-factory at Doncaster, but failed; many other similar attempts failed; and after spending many years and a large fortune, obtained from Parliament a reward of £10,000, as an acknowledgment of the national value of an invention which had brought no profit to its author. One reason why the machine failed for a long time in its object arose out of the circumstance that cotton requires dressing while being woven, and that the wages paid to the man who had to dress the warp went very far to counterbalance all the economical advantages belonging to the power-loom itself. At length Mr. Radcliffe, of Stockport, invented the dressing frame or machine, by which the yarn is dressed before being placed in the loom.

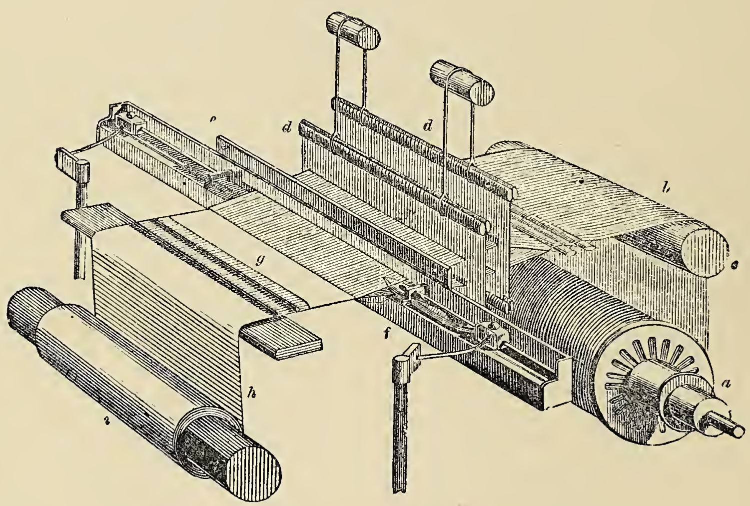


Fig. 70.—The Mechanism of the Power-loom.

a, the roller on which the warp-threads, *b*, are wound; *c*, a small guiding roller, over which they pass to the heddles *dd*; *e*, a "reed" of wires, by which the threads are kept apart; *f*, the shuttle; beneath it is an apparatus, repeated on the opposite side of the loom, by which the shuttle is driven to-and-fro; *g*, *h*, the web passing on to the roller *i*, on which the cloth is wound as produced. Every motion being automatical in the power-loom, the production of cloth is incessant so long as a supply of warp and weft is kept up. The various parts correspond, more or less, with those of the hand-loom shown in Fig. 69.

We have thus traced the history of the power-loom, and shall now point out some of its important parts. It is constructed on precisely the same principles, modified, however, to suit the peculiar requirements of machinery, which, not having the power of recognising any accident, must be made as perfect in detail as human ingenuity can attain. The cut (Fig. 70) gives an illustration of the most essential parts of the

power-loom ; and the subjoined description of its construction, with a comparison of the cut representing the hand-loom (Fig. 69), and the description of that already given, will suffice to explain to the reader its construction and *modus operandi.*

Now such apparatus, when fixed to various pieces of frame-work, and placed in connection with the moving power from a steam-engine, form the power-looms which give such a busy appearance to a factory. In the "shop" sketched in 71, there are 1,200 power-looms, all employed in weaving cotton goods. The noise created by so many machines working near each other is so great as to be at first almost unbearable. The steam-engine sets the whole vast assemblage to work, and effects a number of different movements in each machine. It unwinds the warp from the warp-beam, raises and depresses the treadles, throws the shuttle, drives up the weft-thread after each throw, and winds the woven cloth upon the cloth-beam. In the cotton manufacture each loom is between three and four feet high by perhaps five or six wide, and the looms are so placed that one female can attend to two of them. These females mend the warp-threads when they break, replace the empty shuttles by filled ones, replace the warp-beam when emptied by another containing a new supply of warp, and remove the cloth-beam as fast as it is filled. The power-looms (Fig. 74) connected with worsted-weaving are more complex, being provided with the Jacquard apparatus, of which we shall shortly speak.

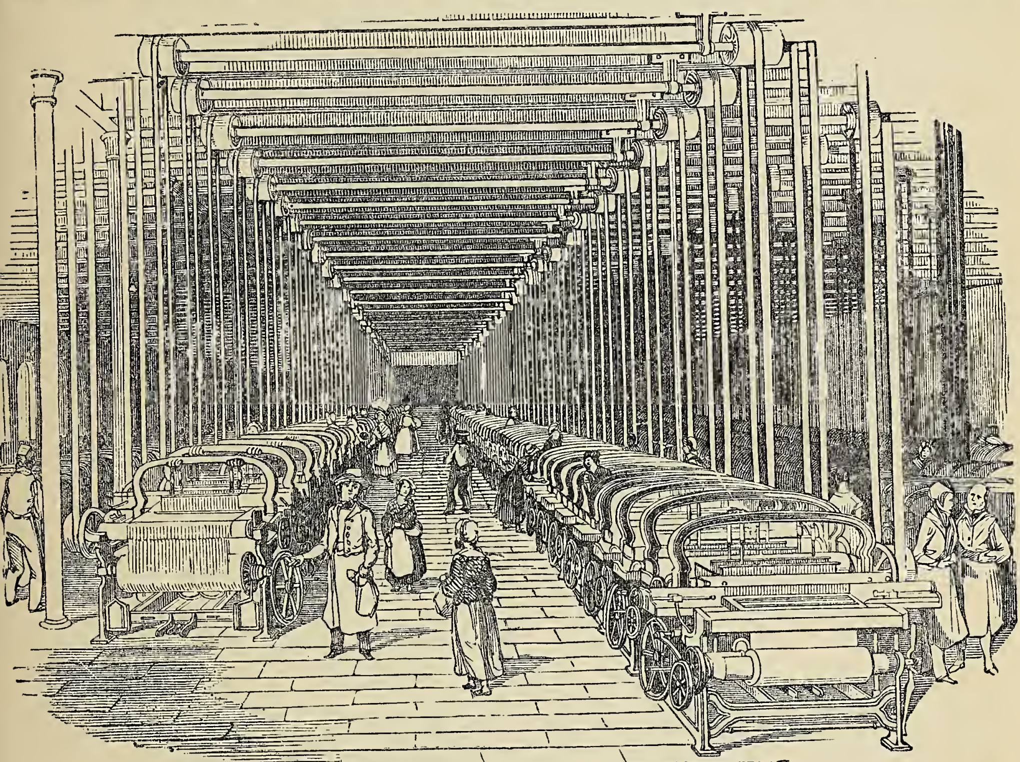


Fig. 71.—Power-looms : Cotton Manufacture.

The most remarkable circumstance, perhaps, connected with the rise of the power-loom is the growth of new villages and towns which accompanied it. There is a spot on the banks of the Mersey, where Lancashire, Yorkshire, and Cheshire all meet, now occupied by some of the largest weaving and spinning factories in the empire, but which, forty years ago, was almost entirely open country. The settlement of power-loom weaving at this spot arose out of the obstacles raised by the operatives to its introduction elsewhere. "The power-loom," says Dr. Taylor, "driven from West Houghton, sought shelter in a secluded nook adjoining to three counties, where there was neither church, magistrate, nor school. Here this branch of industry found a refuge and took root; Stayley Bridge, which seems to have been chosen by the patrons of the power-loom simply because it was neglected and deemed worthless by everybody else, is one of the most remarkable instances of the rapid accumulation of wealth, population, and buildings produced by the cotton manufacture, even in that land of wonders over which this branch of industry has

spread. Many years ago it was a miserable hamlet, remarkable only for the picturesque views from the Old Bank, a steep hill which rises boldly above the north bank of the river, and, before the prospect was shut out by buildings, commanded an extensive view of very rich scenes. The cottagers, in addition to their agricultural pursuits, employed themselves in spinning woollen yarn for the manufacture of stockings. There was only one dyer in the place, and he possessed the solitary piece of workmanship which could be said to make any approach to machinery, which consisted of two wheels turned by mastiffs, similar to the dog-wheels anciently used in kitchens. It is now a flourishing town, with municipal institutions of its own, and extends to some distance on the Cheshire side of the river. The persons employed in the mills and factories have come at different times from the agricultural counties and districts; they are, in fact, colonists, not connected with Lancashire by birth or relationship, and are therefore very slightly influenced by local attachments." But calico weaving has spread not only through South Lancashire, but to Glasgow and other great cotton centres; Manchester, however, being still *the* centre of this branch of industry.

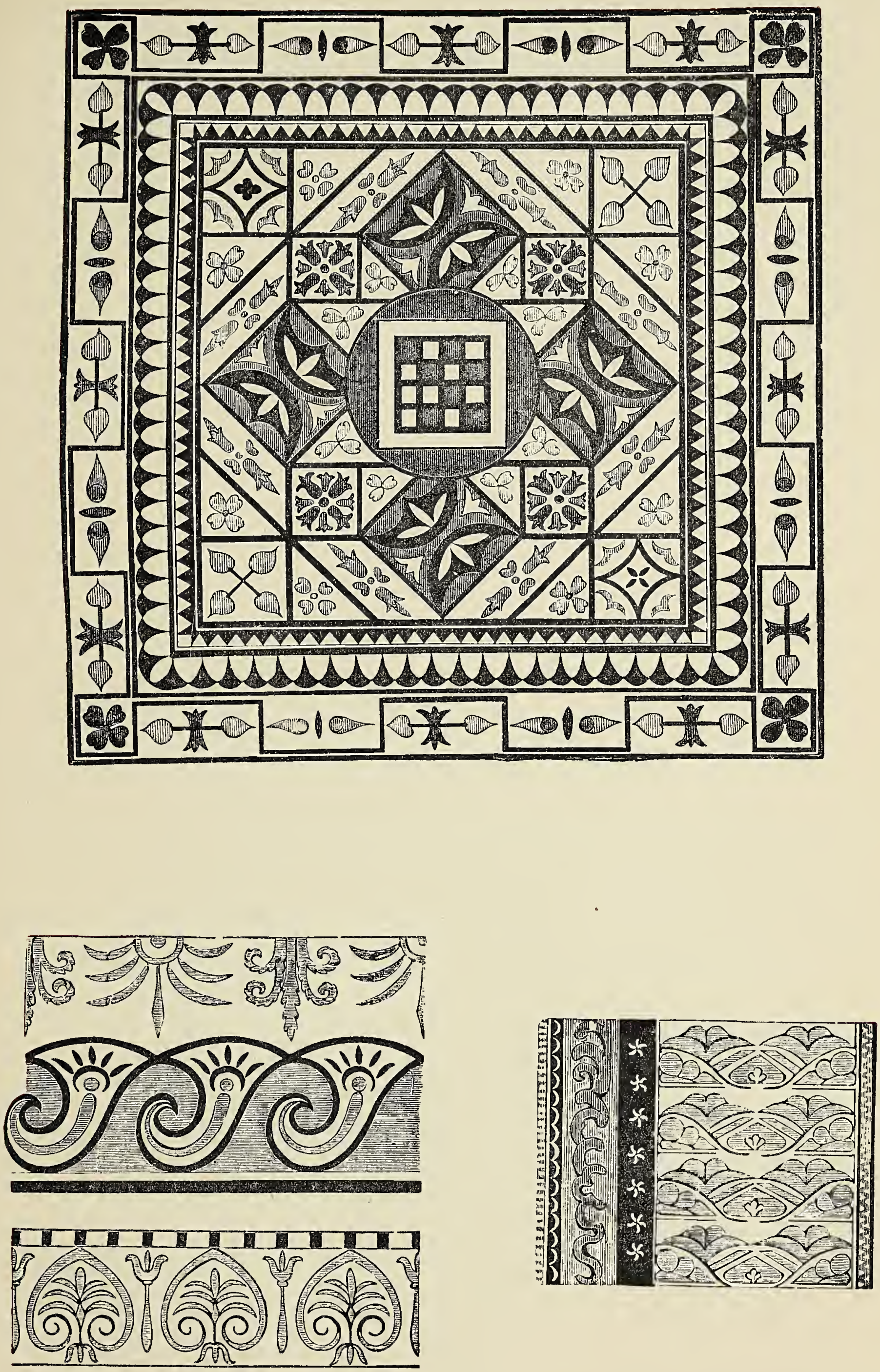
Fancy Weaving—The Jacquard Machine.—We have hitherto dealt with cotton weaving alone, and that in its plainest form—that of making calico. But with cotton, silk, wool, etc., another and most important branch occurs, namely, *fancy weaving*, which includes an enormous number of articles, such as damasks, carpets, etc., etc., in which elegant figured designs appear, and relieve the monotony of the surface.

There are two classes of patterns capable of being produced in weaving: the one with uniformity of colour, and the other with diversity of colour. The former is illustrated by damasks, diapers, and similar goods, made of all the four fibrous materials: there is here observable a pattern of squares, lines, sprigs, diamonds, scrolls, etc. The latter is illustrated by woven goods too varied in kind to need particularizing: if the thread of the warp and the weft be differently coloured, and especially if there be many different colours both in the warp and the weft, a definite arrangement of these will, of course, produce patterns. In all such goods as damask, where pattern is produced without diversity of colour, a careful examination will show that the pattern results from the mode in which the weft-threads are made to cross over or under the warp-threads—in some places crossing over three or four at a time, in others one at a time, in others passing under three or four threads at once, and so on. Even where the threads are variously coloured, the production of anything like a graceful design depends quite as much on the manner in which the threads are made to intersect each other, as on the harmony of the colours.

This kind of ornamental or fancy weaving, then, depending on the mode of interlacement, it is evident that the arrangement of the loom, in respect to the manner of raising and depressing the warp-threads, is the main point to be regarded. In plain weaving, as we have before explained, the warp-threads are divided into two groups, ranged alternately throughout the width of the web or cloth; the one group being raised when the other is depressed, and *vice versâ*. But in fancy-weaving this uniformity of grouping is utterly departed from. In one "shoot" or transit of weft-thread it may possibly pass over ten times as many warp-threads as it passes under; the next time the relation may be exactly reversed; the third time the two groups may be equal in quantity; on some occasions the threads which it passes over may be very nearly all near one edge of the cloth, while in others they may be pretty equally spread over the whole width. All these matters depend solely on the patterns to be produced.

Now, these diversities depend on the manner in which the threads of the "heddles" take up the warp-threads. In plain weaving there are only two heddles, each of which is connected with exactly half of the warp; but in fancy weaving the heddles are more numerous, and each one takes up a quantity of the warp, depending entirely on the pattern to be produced. The threading of the warp-threads upon the heddle-strings, or the "drawing in," as it is called, becomes thus an intricate operation, and occupies a long time. So long as a simple pattern only is required, the arrangement of the heddles is practicable; but for a complex pattern the heddles would be too numerous for the loom to contain, or for the weaver to manage, and another contrivance is therefore adopted. We may take, as three examples of simple pattern, the varieties known as *shots*, *stripes*, and *checks*. A shot-pattern is one in which all the warp-threads are of one colour, and all the weft of another; but the weaving arrangements scarcely differ at all from those in plain goods. A stripe-pattern is one in which there are parallel lines running either along or across the piece of cloth, the stripes being alternately of different colours; if the stripes extend lengthwise of the cloth, the warper introduces different colours into his warp-thread, but the weaver proceeds nearly as for plain goods; but if the stripes be breadthwise, the warper provides only one colour, whereas the weaver uses shuttles containing threads of different colours. A check-pattern combines both forms of stripe, and requires different colours in the warp, and also different in the weft; so that both the warper and weaver have something more to attend to than in plain goods.

When the pattern becomes so complicated as to include flowers, scrolls, etc., some contrivance is necessary to avoid the too great multiplication of treadles in the loom. The *draw-loom*, the *draw-boy*, and the *Jacquard machine*, are three pieces of apparatus contrived at different times for this purpose. In the draw-loom there is an immense number of strings hanging down vertically, with weights or leads at their lower end; and a boy, by pulling these weights, brings the various warp threads into such a position as to receive the weft in accordance with the pattern.



PATTERNS OF WORSTED EMBROIDERY.

All the warp-threads which are to be raised at once are connected with one handle, which the attendant boy pulls at the proper time. The enormous number of strings forming the "harness" of this kind of loom gives it a very complex appearance; and if the boy makes a mistake, by pulling the wrong handle, the weaver's weft-thread becomes wrongly thrown; to obviate this mischief a separate piece of apparatus was contrived, called the draw-boy, and it was to take the office which the boy had before filled. In this machine the weaver's foot pressed upon a treadle, which, by giving a vibratory motion to a lever, drew down some of the warp-threads, and elevated the rest.

But the Jacquard machine is the one which has become permanently established, and which is, year by year, more extensively employed. The history of the invention is a remarkable one, and was given some years ago by Dr. Bowring, to a Committee of the House of Commons on the silk-trade, as detailed to him by the inventor himself.

M. Jacquard was originally a straw-hat manufacturer at Lyons; and it was not until the peace of Amiens that his attention was first attracted to the subject of mechanism. The communication between England and France being then open, an English newspaper fell into his hands, in which he met with a paragraph, stating that a premium would be awarded by a society in this country to any person who should weave a net by machinery. The perusal of this offer awakened his latent mechanical power, and induced him to turn his thoughts to the discovery of the required contrivance. He succeeded, and produced a net woven by machinery of his own invention. It seems, however, that the pleasure of success was the only reward which he coveted, for as soon as accomplished he became indifferent to the work of his ingenuity: he threw it aside for some time, and subsequently gave it to a friend as a matter in which he no longer took any interest. The net was by some means at length exhibited to some persons in authority, and by them sent to Paris. After the lapse of a period, during which Jacquard almost entirely forgot his piece of mechanism, he was sent for by the prefect of Lyons, who asked him if he had not directed his attention to the making of nets by machines. The prefect rather peremptorily desired him to produce the machine by which this result had been effected. M. Jacquard asked three weeks for its completion; at the end of which time he brought his invention to the prefect, and directing him to strike some part of the machine with his foot, a knot was added to the net. The ingenious contrivance was sent to Paris, and an order was thence despatched for the *arrest* of the inventor.

It may seem strange that such a reward should be given for ingenuity; but under the government of Napoleon I., a very despotic way was often adopted of doing that which was, perhaps, well intentioned in the end. Jacquard found himself in the hands of the gensdarmes, who conducted him to Paris so quickly that he had not time to provide any requisites for his journey. When at Paris, he was required to produce his machine at the Conservatory of Arts, and submit it to the examination of inspectors. After this ordeal he was introduced to Napoleon and Carnot, the latter of whom said to him, with a look of incredulity, "Are you the man who pretends to this impossibility; who professes to tie a knot in a stretched string?" In answer to this inquiry the machine was produced, and its operation exhibited and explained.

When Jacquard had thus acquired a reputation for mechanical skill, he was required to examine a loom, on which twenty or thirty thousand francs had been expended, and which was employed in the production of articles for the use of Napoleon. M. Jacquard offered to effect the same object by a simple machine, instead of the complicated one by which the work was sought to be performed; and improving on a model by Vaucanson, he produced the piece of apparatus which has since obtained the name of the Jacquard machine. A pension of a thousand crowns was granted to him by the government, as a reward for his discoveries; and he returned to Lyons, his native town. So violent, however, was the opposition made to the introduction of his loom, and so great was the outcry against his invention, that three times he with the greatest difficulty escaped with his life. The "Conseil des Prud'hommes," who were appointed to watch over the interests of the Lyonese trade, so completely entered into the feeling which prompted this opposition, that they broke up his machine in the public place or square. Jacquard says, that "the iron was sold for iron, the wood for wood, and he, its inventor, was delivered over to universal ignominy." The invention was, however, not lost: the Jacquard machine was constructed elsewhere, and gradually made its way in England and in France, wherever complicated fancy-weaving was to be executed.

The Jacquard apparatus is affixed over a loom, for the purpose of drawing up the warp-threads to form a "shed," into which the weft-thread may be thrown. There is a hollow box, on each of whose sides a great number of holes are pierced. There are also, for each pattern to be woven, a great many oblong cards prepared, the same size as the side of the box, and these cards are perforated in the same way as the box. There are as many cards as there are weft-threads to form one series of the pattern; sometimes amounting to twelve or fifteen hundred. The perforations in the cards, where they occur, correspond in position with some of those in the box; but the number varies greatly, being always less than that of the holes in the box. All the cards are linked together by joints, in such a manner that as the box rotates on a horizontal axis, the cards in succession lie flat in the several faces of the box.

The mode in which these perforated cards aid the object in view, is somewhat difficult to explain; but it may be stated thus:—If each face of the box has, say fifty perforations, then there

are fifty small bars, or needles, ranged in a group, in exactly the same order as the holes in the faces of the box, the ends of the bars being immediately opposite the holes. Each bar is a lever, by which certain warp-threads are governed in such a way, that when the bars are moved longitudinally the warp-threads become elevated or depressed. The box is so connected with other mechanism as to have a movement to and from the ends of the bars in such a manner, that when one of its faces strikes against these ends, the latter will pass into the holes in the box if the face be not covered with a card; but if it be covered, some of the bars will pass through

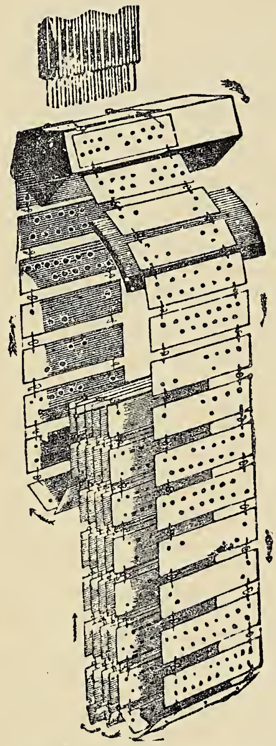


Fig. 72.—Jacquard Pattern-card Apparatus for Weaving.

a, the bars attached to the threads of the warp; *b*, the box perforated with holes, corresponding with holes perforated in *c*, the pattern-cards. These cards, by which the weft is caused to produce the pattern on the web of silk or other material wove in the loom, pass upwards from *d*, over *b*, descending to *c*, and so on—at last again arriving at *d*, etc. They are loosely joined so as to readily fit the sides of the box.

the holes in the card into the holes of the box; while others, at the unperforated parts of the card, will be driven aside. Thus, the bars become unequally acted on, and they in their turn act unequally on the warp-threads, depressing some and raising others.

The cards are so perforated as to lead to the production of a pattern from this inequality of action; and the preparation of cards thus becomes an important preliminary operation. In Fig. 72 we see so much of a Jacquard apparatus as relates to the cards, hinged together at their edges, and passing over a five-sided box at the top: while above them are shown the ends of the rods or bars which are to be acted on by them. In Fig. 73 we see the mode of stamping the holes in the cards. There is an arrangement of apparatus almost as complex as the Jacquard machine itself, for determining the number and position of the holes to be stamped in each card in accordance with the pattern;

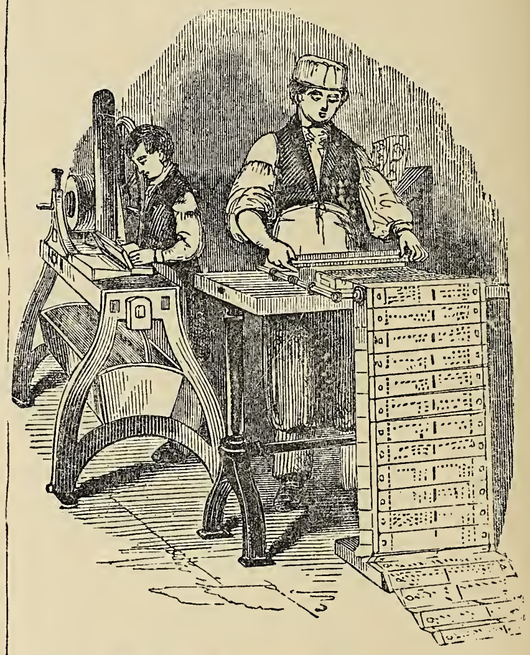


Fig. 73.—Jacquard-card making.

and these positions once ascertained, the holes are stamped at a press, and the cards are hinged together.

In the weaving-gallery shown in Fig. 74, the looms on the right hand are surmounted with the "draw-boy" apparatus, while those on the left have the "Jacquard" apparatus. Every kind of material is gradually coming within the range of this beautiful piece of mechanism, and its value to the art generally is incalculable. In reference to the striking power of this machine, Mr. Porter remarks:—"The elaborate specimens of brocade which used to be brought forward as evidence of skilfulness on the part of the Spitalfields weavers of former days, were produced by only the most skilful among the craft, who bestowed upon their performances the most painful amount of labour: the most beautiful products of the loom in the present day are, however, accomplished by men possessing only the ordinary rate of skill, while the labour

attendant upon the actual weaving is but little more than that demanded for making the plainest goods."

Velvet and Fustian Weaving.—There is a curious texture belonging to velvet, fustian, and a few other kinds of woven goods, showing that there must be some peculiarities in the process of weaving. This texture consists of a soft downy "pile," or "nap," standing up from the surface of the threads themselves, and in most cases quite hiding the threads from view.

In making woven materials of this kind, instead of having only one row of warp-threads, as in common weaving, there are two rows or layers, one above another, and totally distinct. among the threads of the warp, he inserts a thin straight brass wire at right angles to the length of the cloth, or in the same direction as the weft; the wire being so placed as to occupy a position above the warp-threads, but below the pile-threads. The treadle is then worked, the warp-threads are changed in position, and another row of weft shot; the weft passing over the pile threads and half of the warp-threads, and under the remaining warp-threads; by which the wire becomes interwoven or confined among the threads. Two more transverses of weft are made, in the usual way of common weaving, but not interfering with the pile-threads. Another brass wire is then introduced, and entangled among the various threads as

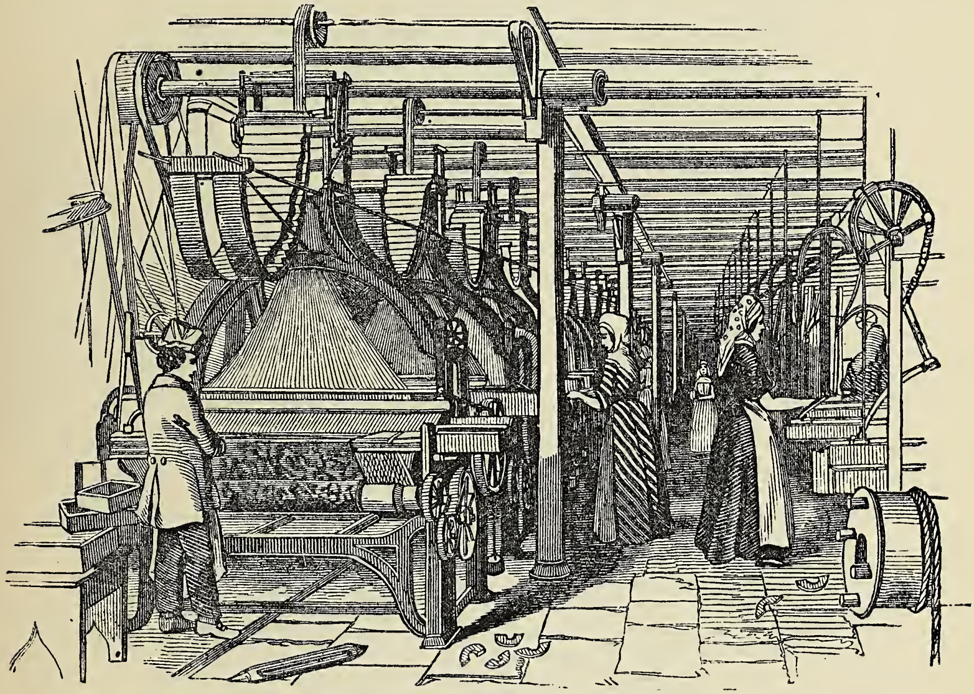


Fig. 74.—Jacquard Power-looms: Stuff Manufacture.

One of these, constituting the pile-threads, is introduced solely for the purpose of producing the pile or nap; whereas the other is the regular warp-thread requisite for the weaving process. If the pile-threads were worked in among the weft, in the same way as the warp-threads, the texture would be simply that of a kind of double silk, but without any pile; the pile-threads are therefore formed into a row of loops, standing up from the surface of the silk; and by cutting these loops with a knife or sharp instrument the pile is produced. The weaver, therefore, has to perform his work so as to leave these raised loops, and this he does in a singular way. After the shuttle has been thrown three times across the web, making the weft interlace three times before; but always observing that the only threads *above* the wire are the pile-threads.

Then ensues the process by which at once the wire is liberated, and the pile of the velvet formed; a process singularly exemplifying the delicacy of hand acquired by those accustomed to the work. Each wire is of a half-round form, or nearly so, and has along its upper surface a fine groove. The weaver passes the cutting edge of a sharp instrument, called a "trevat," quickly along the groove, so as to sever all the loops of pile-thread passing over the wire. The wire is liberated by this means, and is again woven in among the threads as a means of producing new loops. There is always one wire remaining in the piece, and this wire is not

extricated until another one has been introduced. This operation is very surprising, since there are forty or fifty of these cuts made to every inch of cloth, and if the knife were to slip at any one of them, it might do irreparable injury to the piece. The complication of the proceedings, too, is very great, for the weaver has to manage two shuttles, the wires, and the cutting "trevat."

We are indebted to Mr. G. W. Tomlinson, of Huddersfield, an exhibitor in the Woollen Exhibition at the Crystal Palace, in 1881, for the following remarks and illustrations :—

The first operation in dressing or finishing woollen cloth is to *burl* it—*i.e.*, it is passed over tables raised at a convenient angle to catch the most light, and all knots and irregularities in the yarn are picked out by women called "*burlers.*"

The cloth is then *milled*, an operation requiring considerable judgment. The grease is partially cleared out in this stage, and the cloth felted together, and the required width of the cloth is obtained. This was formerly done by the old fulling stocks with beaters, but they have now been almost entirely superseded by milling machines, which full the cloth to the required substance with less waste in weight, and with less soap. In very remote times this felting was done by men stamping on the cloth with their feet, and the stocks were known in their earlier history as walk-mills, a name still obtaining in Scotland and Germany. The name Walker is supposed to be derived from this trade. The milling-machine is more economical in all ways, requiring less power, and no foundations (see Fig. 75).

After milling, the cloth is next taken to the washing-machine, where it is thoroughly scoured and cleansed from all grease and dirt, and other impurities. This process requires a plentiful supply of soft water. The washing-machine consists of a large roller in the centre, 5 feet wide and about 24 inches in diameter, the upper roller, revolving by its own weight on the lower one, varies from 28 inches to 34 inches. Great care has to be exercised in the choice of the wood for these rollers, to get it thoroughly sound. The top roller, in some cases, is made of cast iron, and this seems to answer very well. Then comes the operation known as tentering, where the cloth is dried and stretched out to the required width. There is some danger of over-tentering a piece, known technically as *baking* it; this is overcome by the use of the dewing-machine, which, by throwing an imperceptible film of water over the cloth, restores it to its originally full and soft feel (see Fig. 80). We now come to *raising*, which formerly was done by hand, but is now on the raising-gig. The work is most effectually performed by means of the teazle (*Dipsacus fullonium*), a plant which grows in Yorkshire, and some parts of France. The teazle is fixed into an iron frame known as a gig-rod; twenty-four of these rods are put around the cylinder of the raising-gig, and, when revolving at full speed, they offer a surface of remarkable power for raising the nap of the cloth. The amount of contact the piece requires varies very considerably, and is regulated by means of a moveable breast-roller, which can be raised or lowered by means of a rack and pinion (see Fig. 76).

The next process is *shearing*. The cloth, as it leaves the gig, presents a very unequal appearance, the raised points of wool being of uneven length. Formerly this work was done by croppers, who cut the surface of the cloth by means of shears. These men were skilful, but as the trade was virtually a monopoly, they presumed to an intolerable extent on their own value; and when the perpetual shearing-machine was invented, serious riots followed, often ending in bloodshed and the gallows. Happily, all this is at an end, and the perpetual shearer has become established. Great care is required in this machine; firstly, to have the cylinder, which is clothed with spiral knives, perfectly true; secondly, to have the blade or under-knife

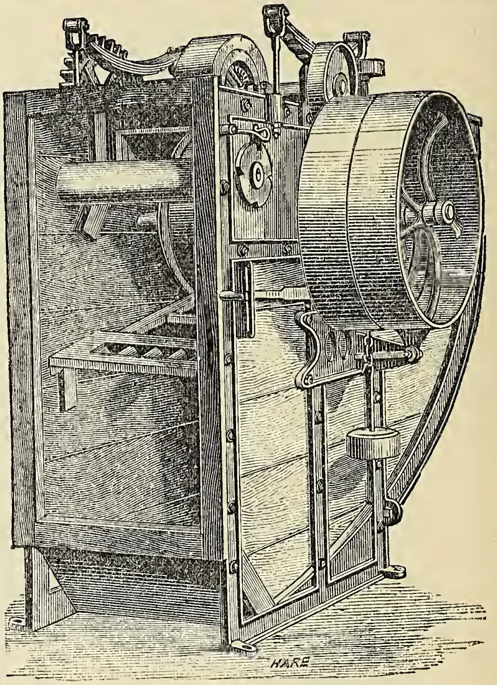


Fig. 75.—Milling-machine.

ground to a suitable bevel; thirdly, to have the bed adapted for the kind of cloth. A useful adjunct to the shearing-machine is the grinding-machine, which becomes almost a necessity when one man has to follow several machines. It is obvious that the shearing-machine will vary considerably, as the articles it is called to operate upon vary; and sometimes they have brushes to brush the back or front of the cloth, iron setting-up rollers, with cards, cuttling motion, etc. (see Fig. 77).

After shearing, the cloth is taken to the brushing and steaming-mill. The tendency of late years has been gradually to improve the quality of the brushes, or, rather, to increase their strength; in worsted coatings this is especially necessary, because when smartly brushed before cutting, the pattern is brought out with

great distinctness. After brushing, the piece is generally cut again (see Fig. 78).

After cutting a second time the cloth is usually run over the dewing-machine, and then goes to the press. The operation of pressing is as follows: the piece is doubled into folds about 36 inches by 32 inches, and between each fold a sheet of millboard is inserted. The piece thus papered is put into the press; on the top is placed a paper fencing, then a sheet-iron one; on the latter are placed three cast-iron press plates raised to a considerable heat, and fencings being put on the top, the next piece can be put on; this is repeated until the available press-room is filled, 8 or 10 pieces going into the space; the pressure is then put on by means of a hydraulic pump, usually working to 2 tons on the inch, which on a 12-inch press would give a total pressure of 226 tons. The goods thus packed are allowed to remain in the press all night, and in the morning are ready.

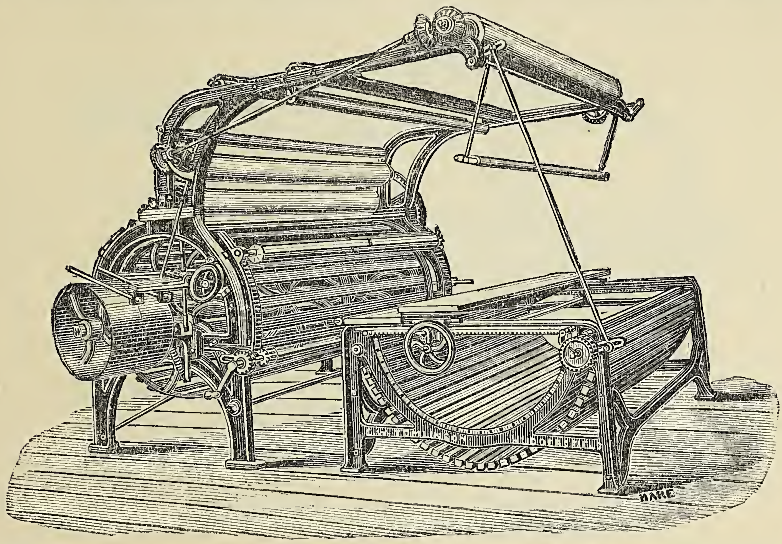


Fig. 76.—Raising Gig, with revolving Turntable Scray, and Expanding Breast-roller.

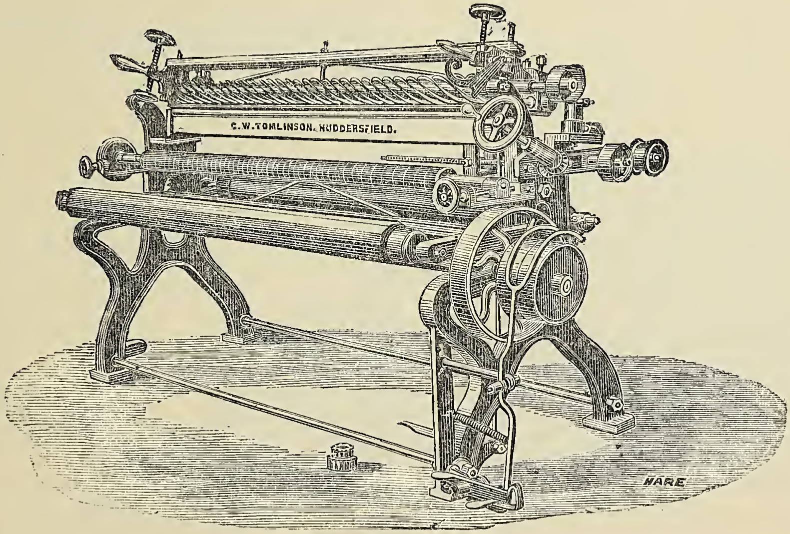


Fig. 77.—Broad Shearing-machine, with one extra Piling or Setting-up Roller. (66 inches wide.)

All these processes require much judgment on the part of the finisher, because he has to overcome or conceal the defects that may have

arisen in the progress of the manufacture of the piece. This is especially the case in goods of low quality, where the finish of the article is its chief recommendation.

The finishing of faced goods is a more serious business, requiring all the above ma-

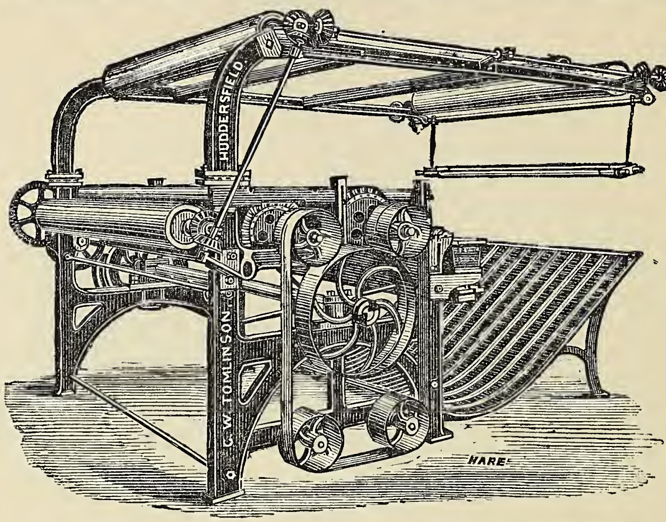


Fig. 78.—Double Brushing and Steaming Mill. (72 inches wide.)

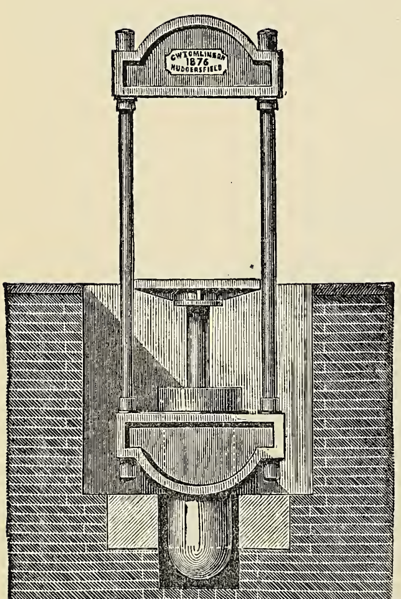


Fig. 79.—Hydraulic Press.

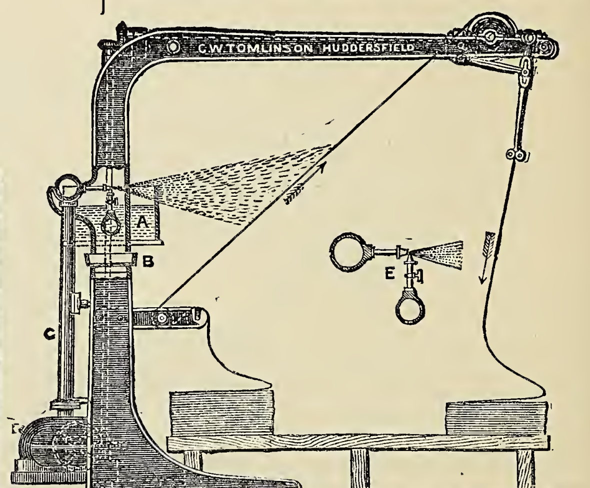


Fig. 80.—Dewing-machine.

chines, and others besides. This process is known as the wet finish, and, after pressing, requires to have the cloth wound tightly on to birch rollers (requiring a winding-on frame for the purpose); it is then boiled in water for some time, then it is dyed; after that the processes are as follows: raising, tentering, setting up (with brush), cutting for the third time, cross-cutting on the Lewis or cross-shearing machine, brushing, burling, pressing for the second time, steaming and brushing, and finally cold-flatting—that is, the piece is papered as before, but pressed cold. In short, the cloth has to go through each operation about three times, and is boiled as well. The result is a fine lustrous appearance, which remains as long as there is any wear in the cloth. It is objected that all these different processes tend to diminish the body or the strength of the cloth; this is doubtless the case to a certain extent, but in woollen cloth, as in other things, high finish is seldom required along with great strength.

CHAPTER II.

DYEING, BLEACHING, CALICO-PRINTING, ETC.

THE art of dyeing is of course of great antiquity. Nature itself suggests it. The colours of flowers give an idea of ornamentation that human nature could scarcely help following. There seems to have been a kind of innate propensity in mankind to adopt the idea and practice to the purposes of ornamenting both the bodies and clothing. Hence in savage lands we find the practice of tattooing largely followed. No matter what part of the world we choose to examine, the idea of dyeing, or the production of a variety of colours, by the union of mechanical or chemical agents, seems universal.

It is almost unnecessary to state that the ancients were entirely unacquainted with the chemical principles on which the art of dyeing is carried on. In the following remarks instances of this will be abundantly given.

That the art of dyeing was known and valued among early nations, is abundantly clear. The allusions to "purple and fine raiment," to "dyed garments," to "cloth of many colours," etc., are numerous in the Bible. In a work by the late Dr. Kitto, after an allusion to the antiquity of this art, and to the pre-eminence attached by the ancients to *purple* beyond every other colour, it is remarked :—"It is important to understand that the word purple, in ancient writings, does not denote one particular colour. Pliny mentions the difference between some of the purples: one was pink, approaching to a scarlet, and that was the least esteemed ; another was a very dull red, approaching to a violet ; and a third was a colour compared to coagulated bullock's blood. The most esteemed Tyrian purple seems to have been of the last colour ; we say the most esteemed, because it appears that even the Tyrian purple was not one particular colour, but a class of animal dyes, as distinguished from vegetable, varying in shades of purple, from the most faint to the most intense. It is to be understood, however, that the Tyrian purples were more esteemed than any other colours, although they differed in degree of value. Of the vegetable purples we know nothing ; most of the information relates to the purple of the Phœnicians : their dye was obtained from several varieties of shell-fish, comprehended under two species—one (Buccinum) found in cliffs, and the other (Pupura, or Pelagia), which was the proper purple, fish taken at sea. The first was found on the coasts of the Mediterranean and Atlantic, and locally differed in the tint and value of the dye which they furnished. The Atlantic shells afforded the darkest colour ; those of the Italian and Sicilian coast, a violet or purple ; and those of the Phœnician coast itself, so general on the southern coast of the Mediterranean, yielded scarlet colours."

In respect to calico-printing, the ancients seem to have been well acquainted with the art of producing a coloured pattern on cloth. Homer notices the variegated linen cloths of Sidon, a magnificent production. In India the art has been practised for ages, and it derives its name of Calico-printing from Calicut, a town in the province of Malabar, where it was once extensively carried on. Herodotus, who wrote more than four hundred years before the Christian era, says that the inhabitants of Caucasus adorned their garments with figures of animals, by means of an infusion of the leaves of a tree, and the colours thus obtained were said to be very durable.

Clever as were the ancients in the art of dyeing, the results they obtained arose from long experience, and blind practice, and as such were simply empirical. In the perusal of the following Chapter it will be seen that dyeing, bleaching, etc., are now intimately connected with a knowledge of science, especially chemistry. Consequently the results that the modern dyer obtains may at all times be certain, provided proper precautions, founded on scientific teaching, be attended to. But science has done more than this. It has opened out an entirely new range of matters, which have enabled the dyer to produce colours generally unequalled by those obtained from the vegetable kingdom, which, generally speaking, were fugitive in their character.

The early history of the art of bleaching has been fully detailed in the Introduction to this work, in Vol. I., at page xlviii. ; we shall therefore now proceed at once to discuss the practical details of the subject that have to be dealt with in this Chapter.

Nature of Colours.—In the first place we must notice that colour is not an inherent, but rather an accidental, property of bodies. For example, if we arrange together some light-blue, pink, and yellow ribands, we find, so long as they are viewed by ordinary light, their

individual colours are palpable to the eye. If, however, they are seen by a single-coloured light, or, as it is termed in science, a monochromatic, they will appear all nearly of the same colour; and, indeed, will only vary by light and shade rather than colour. This is easily proved by taking the coloured ribands into a dark room, and then viewing them by means of a light produced by burning spirits of wine and common salt together.

Again, whatever colour a body may seem to have by ordinary solar or artificial light, if placed in any colour of the prismatic spectrum, it will at once assume the latter. This is easily tried by causing the light of the sun to pass through a flint-glass prism, and receiving the rays on a sheet of white paper. Thus any coloured object can be introduced successively into each ray of the spectrum, and the effect just mentioned will be observed. When, therefore, we philosophically explain the cause of colour, we state that it is owing to the absorption of all other colours but that reflected to the eye. Thus, in a red substance, we consider that the blue and yellow rays are absorbed, whilst the red are reflected; and so on for each other colour in the spectrum.

It would seem, from our constant experience, that the number of colours is exceedingly great. And so compound tints are, yet the primary may be reduced to seven according to the old notion —namely, violet, indigo, blue, green, yellow, orange, and red. But it is evident that these may be still further reduced; and we now reckon them as three only. It is certain, for example, that orange may be produced by combining a yellow and red; green by similarly dealing with blue and yellow; purple by uniting red and blue. This is not only true philosophically, but is also followed practically; as, for example, in dyeing cloth green, when substances affording, separately, yellow and blue colours, are employed.

There is no better plan to study the law of colour than the use of the polariscope, by which the most splendid tints can be observed in certain transparent substances; and by this means, and that of the prismatic spectrum, obtained by passing light through a flint-glass

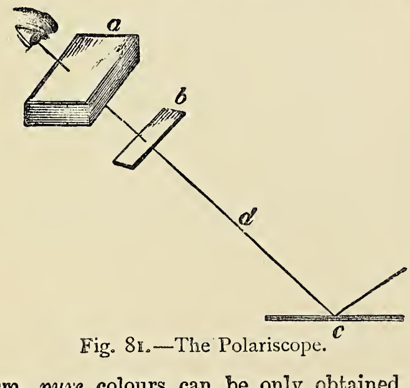


Fig. 81.—The Polariscope.

prism, *pure* colours can be only obtained. A polariscope is easily constructed by painting one side of a piece of plate-glass with black varnish, which, when dry, will act as a reflector; and, for the purpose of experiment, is so placed that diffused daylight may fall on it through a window, at an angle easily formed, as we shall presently describe. Seven pieces of thin clean window-glass are then to be bound together so as to form a flat bundle—say an inch wide, and three inches long. The mode of using this simple apparatus is represented in Fig. 81; in which *a* illustrates the bundle of plates just named, held cornerwise, so that they may be looked through at an angle in the line *d c*. The blackened plate, with its uncoated side upwards, is placed as at *c*. If the bundle of plates be looked through, and turned slowly round in a circle, it will be noticed that the light is diminished twice successively, as reflected from *c*—namely, when at an angle of 90° and 270° with the first position. If a piece of thin mica, or that substance split into plates by having been heated, be placed at *b*, the most gorgeous display of colours will be presented. If, now, the bundle of plates be slowly turned round, instead of the light being simply diminished, it will be seen that the *nature* of the colour seen will be changed. Where there had previously been a violet, a yellow will appear; in place of blue, an orange; and, instead of green, red is observed: and these colours are again changed to the original, on the bundle of plates arriving at angles of 180° and 360°, or its first position.

By this simple piece of apparatus, therefore, we have a means not only of viewing most beautiful colours, every variety of the tints of which may be produced by regulating the thickness of the mica plate—the thinnest giving blue, and the thickest red—but also of ascertaining the opposites of each colour, or, as it is termed in science, the *complementary* of each.

Let us explain the practical value of this fact. If the eye long view a piece of bright yellow paper, that colour so affects the optic nerve, that when the head is turned away, all objects present a bluish or violet colour. If a dark red or orange-coloured paper or wafer be steadfastly looked at, immediately afterwards surrounding objects will present a greenish or bluish tint. Now this arises from the complementary colour being presented to the eye, or rather being distinguished by it, owing to the previous over-exertion it had suffered by watching the primary colour in each case. It is precisely on this principle that bleached cotton yarns, when packed in bundles, are usually surrounded with blue paper. After the cotton has left the bleacher's hands, unless slightly blued, it has a yellowish tint; but, by packing it in blue paper, that tint is neutralised to the eye. Similarly, if the dyer send out goods of a yellow colour in blue paper, red in green, and violet in yellow, the colours he has produced will look much more brilliant than if merely placed on white paper. The science of this, therefore, we have here explained, because although the *practice* is common enough, the reason is but little understood. The following is a list of

colours complementary to each other; but by using the polariscope in the manner just directed, each colour and its complementary may be instantly found.

Complementary Colours.

Violet and Yellow.
Blue ,, Orange.
Green ,, Red.

We may now explain *why* these colours are complementary to each other.

When light has passed through a prism, it is divided into several coloured rays, as we have already noticed: and the red is at one end; the blue at the opposite; and the yellow between the two. It hence follows, that what we call white light is made up of different colours; and a complementary colour is that of which any one is deficient to make white light. Thus, when bleached cotton yarns are placed in blue paper, the yellow tint of the goods and the blue of the wrapper unite, and convey to the eye an impression of much purer white than would otherwise be seen. How much is science, in its various aspects, involved in our daily life!

It will have been noticed that it is impossible to match colours properly by artificial light, and this is entirely owing to principles already explained. We observed, at p. 86, *ante*, that monochromatic light exhibited every colour alike. There is no distinction except that of light and shade. Now, to a certain, although modified extent, artificial light—such as gas, candles, &c.—has the same quality. All our artificial illuminating agents have too much of the yellow kind of ray to exhibit colours either in the same kind or intensity as we observe them to possess in solar light. Hence blues become greens; yellows have more of an orange tint than natural; and often results of a similar nature accrue, giving a falsity to colour-appearances under such circumstances.

It is a matter of great importance to the practical dyer to become acquainted with all the circumstances of his occupation—a requirement, we regret to say, there is too much reason to believe, is by no means universally fulfilled. It is too frequently the case, that he who is entrusted with the duty of producing the most beautiful effects of art, is often utterly ignorant of its principles. These are not simply scientific, in the usual acceptation of the term; but frequently are connected with matters of a more purely imaginative nature. It is true, that, of late years, schools of design have done wonders in improving the taste; but much is yet left to perform. A great fault of many engaged in the production of dyed, printed, and other such matters, is the want of a keen sense of propriety in the distribution and aggregation of colours. We feel precluded from entering further into this question, partly because it is beyond the scope of this work, and also because, in the polariscope (described at the previous page), we have suggested that which might remedy any defect in this respect. The willow pattern of our plates was long enough a disgrace to our power of art designing; but we must confess that the arrangement of glaring, and utterly unsuitable combination of colours in printed cotton fabrics, is too frequently a standing rebuke to our progress in that direction of illustrative design. We might point out many other cases of the same kind where the arrangement of colour is involved; as, for example, in paperhangings, carpets, printed silks, &c., &c.: in all of which there is not only great room for improvement, but, at present, a vulgarity and utter want of taste, which cast great discredit on such branches of manufacture. The Chinese and Japanese frequently excel us in such respects: and we have too frequently to find our own defects when comparison is made of British productions with those of France, Italy, and other competing nations.

Heat.—The arts of dyeing, bleaching, printing, &c., involve many other branches of science, in their exercise, besides that of optics; and one of the most important of such applications is that of heat. It rarely happens that any economic process can be carried on without the agency of that force. It facilitates solution and chemical action in general; and these are amongst the most common operations of the arts under consideration.

In former times, fires under "coppers," or other heating vessels, were of universal employment, although the doctrines of latent heat have been long thoroughly understood. Yet, slow, indeed, is the progress of improvement arising from scientific principles. As a rule, direct application of heat from the combustiou of fuel—as in a furnace beneath a vessel in which goods are boiled—is a very expensive method of heating. Hence, in all large establishments boilers are erected, the steam from which is conducted into the vessels containing the dye-stuffs to be heated. Frequently the steam is utilised by allowing a coil to pass into the vessels; or by having an external one, through which the steam passes without entering at all into the vessels holding the goods. The advantage of this method consists in its not adding to, and, therefore, diluting the liquor, which, of course, must result if the steam from the boiler be allowed to blow into it. Independently of this, the steam, if under high pressure, would frequently drive out and waste the contents of the vessel into which it is allowed to issue.

The economy of this mode of heating liquors arises from the fact, that one pound of steam gathers and retains caloric sufficient to raise five and a-half pounds of water to a temperature of 212°, or the boiling-point. And, therefore, just as we use straps to communicate power from the shafting to the machinery of our factories, so steam may be employed as an economic vehicle for the conveyance of heat. By such means it is now also universal to dry goods that have been either dyed or bleached; the waste steam of the engine, if one be used, or that supplied direct from a boiler, and distributed through pipes laid at the lower part of the drying-room, being used for that purpose. And here we may give some useful hints

to those who may propose extending their present, or erecting fresh drying-rooms.

It is a very common, but ridiculous error, to suppose that heat has a drying effect *per se.* Indeed, it has a directly opposite effect under certain circumstances. Thus, if a quantity of wet cotton-wool, &c., be placed thickly on the top of a boiler, and *no current of air* be permitted to take place in the shed or room, drying progresses very slowly indeed. We have seen two hundredweight of cotton, under such circumstances, require two days to become thoroughly dry, when spread out on York paving that covered three thirty-horse steam-boilers; when, at the same time, side flues assisted, besides the heat of the steam, in producing a high temperature of the atmosphere in a *closed* room above them. The working pressure of steam was thirty-five pounds per square inch, and hence the radiated heat from the boiler surface was great. After erecting light framework, on which the cotton-wool and hemp were placed; making an aperture in the roof; and creating a current by openings at the bottom of the room, and the issue of a jet of steam through a funnel at the top, from a pipe of an eighth of an inch in the bore, the drying powers of the apartment were increased upwards of twentyfold, simply because a constant ascending current of air was thus produced.

The retentive power of moisture possessed by atmospheric air, is *generally* in proportion to its temperature; hence, on a hot "muggy" day (to use a common phrase), the air is so loaded with aqueous vapours as to be incapable of drying, under ordinary circumstances. At such times, it will be noticed that the waste steam from an engine appears as blown into the air—*e.g.*, from a locomotive—in much greater bulk and quantity than when the air is drier. As the temperature of the air decreases, its capacity for moisture lessens; hence the principle of many kinds of hygrometers, which indicate the amount of moisture present in the air by the difference of temperature between a bulb of a thermometer artificially cooled, and one exposed to the atmosphere without such an appliance. It is familiarly known in this country that an easterly wind is a dry one, because, being destitute, comparatively, of moisture, it rapidly absorbs aqueous vapours from the bodies over which it passes. On the other hand, the south and south-westerly winds, being loaded with aqueous vapour, possess little or no drying powers.

Air in motion, again, even if moist, has much greater drying powers than when stagnant; and, for this reason, the increased drying powers of a current of air are caused in the manner illustrated in the case we just adduced. The common practice of "blowing" the tea in a saucer, to cool it, is a familiar illustration of this fact, for we thereby cause a more rapid evaporation of the moisture by constantly bringing fresh air to the surface of the evaporating fluid. The law of *convection of heat* may here be named, as being involved in the operations of both heating and drying in dyeing, and such similar processes.

By convection, we mean the power that fluids have of carrying heat upwards when they are raised in temperature. The nature of this power is easily understood if we note the usual method we adopt for heating liquids. Heat is never applied at their upper surface for that purpose, but at the lower part of the vessel that contains them; for then, as portions become warm, they expand, become of less specific gravity than those which are cool, and so rise to the top of the vessel. The cold liquid descends until it comes into contact with the heated part of the vessel; and thence, being warmed, rises to the surface. By such means a constant circulating current is maintained. For such reasons, therefore, steam or hot-water pipes are placed at the lower part of a drying-room; and steam is either driven into the bottom of the liquid to be boiled by it, or the worm and pipes conveying it for that purpose are also there placed. In either case, the air of the room, or the water of the vessel, becoming heated, is specifically lighter, and they therefore rise. The communicated heat is thus, by convection, spread first upwards, and then, by general circulation, in all directions; and therefore heating, warming, or drying, is readily and effectually carried on.

In applying steam for any of the purposes that have been mentioned, much economy of fuel may be effected by attending to the laws of the radiation and absorption of heat. It is by no means uncommon to find them utterly neglected, even in establishments where a knowledge of pure and applied science is of the utmost importance in other respects. Steam-boilers, for example, are erected in the open air, and their upper surface is left entirely uncovered, by which a great amount of heat is wasted, and, of course, therefore, fuel is unnecessarily and wastefully consumed. The pipe conducting steam to the vats, tubs, or engine, is equally left unprotected; and hence the condensation of steam, and loss of heat by radiation, is very great. It is surprising how much neglect in this respect is common. On board our steam-vessels, it is frequently noticed that the steam-boiler and pipes have no protective covering whatever, although felt is occasionally used for that purpose. In our locomotives, the covers of the cylinders are frequently left bare; hence the necessity of continually blowing out the water that collects in them. It is quite a rare case to see the cylinders of our factory engines coated to prevent heat-radiation; and in all such cases, a wilful, and, let us add, disgraceful, waste of fuel and heat is consequent.

In the drying-room, precisely such "wasteful" conditions *are* required; and hence a dark, rough surface of the steam-pipe is desirable, because such a condition is favourable to the radiation and distribution of heat. Polished surfaces are bad radiators and absorbers of heat; and hence would be undesirable for such purposes as warming or drying. Some idea of the effect of surface in radiating heat, may be gathered from the fact, that one coated with a thin layer of lampblack, will diffuse, in the

same time, nearly seven times as much heat as polished iron; hence the great importance of attending to such laws and conditions in manufacturing processes. It frequently happens, indeed, that the success or ruin of an establishment depends upon such circumstances. We have now in our mind's eye, a factory in which three times as much coal is used daily than is needful for driving a six-horse engine, because several unnecessary bends occur in the steam-pipe from the boiler; to which may be added the fact that the pipe is utterly unprotected by a non-conducting coating. We have seen, under similar circumstances, a pressure of steam in a boiler equivalent to forty pounds on the square inch, reduced to twenty pounds as it passed into the cylinder; the difference of pressure, and, therefore, the fuel employed to produce it, being cast away into the atmosphere as waste, through an utter ignorance of scientific principles. Indeed, some years ago it was gravely argued, that a benefit arose from thus letting down the pressure of the steam, as it thus *acquired a greater expansive power in the cylinder!!* Of course, a precisely opposite opinion is now prevalent amongst scientific engineers, who endeavour, by super-heating the steam, to increase its temperature as much as possible, and thus to utilise, to the utmost extent, the heat of the fuel.

In using steam for heating and drying purposes, it must be remembered, that although we may increase its temperature far beyond 212° in a closed vessel, still, its latent and sensible heat form *nearly* a constant sum. Watt enunciated this law in the following terms:—"The same weight of steam contains, whatever may be its density, the same quantity of caloric; its latent heat being increased nearly in proportion as its sensible heat is diminished:" and the reverse holds true. This law requires some slight modifications in theory; but practically it may be considered as correct: hence it follows that no advantage is gained by employing very high-pressure steam for boiling liquids, or for drying by means of steam-pipes. The following table may be of value to some of our readers, as giving the temperature of steam for each half-atmosphere of pressure beyond that of the normal atmospheric pressure, as indicated by the barometer, and being equal to about fifteen pounds per square inch.

Pounds.	Atmospheres.	Pressure in Inches of Mercury.	Temperatures Fah.
15	1	29·8	212·0°
22½	1½	44·7	234·0
30	2	59·6	250·3
37½	2½	74·5	264·2
45	3	89·4	275·0
52½	3½	104·3	285·3
60	4	119·2	293·4
67½	4½	134·1	302·0
75	5	149·0	309·2
82½	5½	163·9	316·4
90	6	178·8	322·7
97½	6½	193·7	328·5
105	7	208·6	334·4
112½	7½	223·5	339·3
120	8	238·4	343·6

As a rule, heat increases the solvent action of liquids in respect to solids; from which there are some exceptions that, however, need not be here noticed, because they do not occur in any branches of chemical operations or processes that are the subject of our present remarks. Chemical action is also greatly aided by heat, for reasons apart from the increase of solvent action occasioned by that agent. Thus, a piece of cotton that would take some time to bleach in a cold solution of chloride of lime or bleaching powder, is almost immediately whitened if immersed in such a solution at a temperature of 212°. Hence, in the great majority of cases, great economy of time and material may be effected by employing a high temperature. For extracting the colour of most vegetable dye-stuffs, heat is absolutely essential, as cold water has little or no effect on them. Apart from the aid it renders to both solution and chemical action, it has also the effect of driving off a film of atmospheric air that attaches to all substances, and, in fibrous materials, becomes almost fixed in their interstices. Thus, if a hank of cotton yarn be cast into cold water, it will float for days. If, however, it be pressed for a short time beneath the surface of boiling water, a large quantity of air will be driven off, and it will speedily sink to the bottom of the vessel. For want of attention to this fact, many common or low-priced dyes are most unevenly diffused throughout the material to which they may have been applied. At the present day, it is customary to pass the "goods" between rollers during the process of dyeing; and hence the liquid becomes evenly diffused, and all parts of the yarn, &c., are attacked by it.

Another, and very extensive use of steam, is that of exposing goods, after they have been dyed, to its action in chambers filled with it. The resulting effect is well known, but the cause is by no means so clearly understood. As, however, access of atmospheric air is permitted simultaneously with the use of the steam, we may suppose that heat and partial action of atmospheric oxygen are chiefly the means of affording the result.

One effect of heat, of an interesting nature, although not often used in practice, is that of its equalising the strength of a solution, infusion, or decoction, in every part of the vessel containing it. With scarcely an exception, water becomes of greater specific gravity when any liquid or solid is added to it. Thus, if a muslin bag, containing a few crystals of blue vitriol (sulphate of copper), be hung in a tall glass vessel of cold water, it will be noticed that a downward current of the dissolved blue salt will be produced; and if the whole be left undisturbed for a few hours, all the blue solution will be seen at the *bottom* of the vessel, because it is of greater specific gravity than the super-jacent water. If, however, the vessel be now placed in another of hot water, the *whole* liquid will become blue, because an upward current is generated by convection, as already explained for other purposes at page 363. Practically, this tendency to produce layers of different strength,

from difference of specific gravity, is not often noticed in the dye or bleach-house. We have seen it, however, operative on several occasions, and once sustained some loss through neglect of this kind. A large quantity of raw cotton had been put into some vats of tepid solution of chloride of lime over-night. By morning, of course, the solution had become quite cold, and the stronger portion had sunk to the bottom of the vessels. There the cotton was over-bleached, and, in fact, materially injured in the fibre, whilst that at the top was scarcely changed in colour. The hint may not be without its practical value to many of our readers ; and the remedy—equal diffusion by heat of the strength of the solution—is readily applied.

In making solutions, infusions, decoctions, &c., this, however, should be carefully kept in mind ; and, also, the position in the vessel of the substance to be acted on. If, for example, a quantity of copperas be cast into a tub of water, it will, of course, sink to the bottom. The layer of liquid just over it will soon become saturated with it, and solution will then stop. Had the same solid been suspended at the top of the liquid, solution would go on until all the copperas was dissolved, because successive portions of fresh unsaturated liquid would come constantly into solvent action. Woody matter, such as logwood, and other articles in chips or powder, are, therefore, more readily acted on, and their colouring matter more speedily extracted, whether by aid of heat or not, if they are thus suspended at the top of a liquid in a vessel.

Lastly, in connection with the question of heat, we must remind the practical man of the difference that temperature makes in the specific gravity of liquids. It frequently occurs that this is a measure of the strength of an infusion or other dye preparation ; at least, it may, and very often should be. We are quite aware of the numerous circumstances that qualify a test of strength of this kind ; and are equally so of the consequences of their neglect. Blind experience frequently and effectively supplies the place of scientific knowledge ; but no person can be the worse for possessing the latter. If, for example, a certain amount of any drysaltery—say copperas (sulphate of iron), blue vitriol (sulphate of copper), and many other saline matters—be dissolved in water, the specific gravity of the solution may be, and indeed always is, a test of its strength ; and if the solution be heated in proportion to the temperature, the apparent specific gravity is lessened. It is usual to estimate specific gravity of all bodies—solid, liquid, or gaseous—at a temperature of 62° of Fahrenheit's thermometer ; and, therefore, it is essential that, in comparing one result with another, such a rule should be kept in mind.

The details of the dye and bleach-house, however, are not such as to require complete scientific accuracy ; and many years will elapse before such is made a *sine qua non* in the operations there carried on.

Water.—An abundance of pure soft water is absolutely requisite for any works in which processes involving chemistry are carried on. As the cheapest of all solvents, it is all but universally applicable. By its conversion into steam, it becomes the best mode of heating and drying, as we have already shown ; and for the purposes of washing and cleansing it is invaluable ; and no other liquid can be economically substituted for it. The dyer makes all his coloured liquids by its agency, with but trifling exceptions ; and hence nothing can be more important than an unlimited supply for him, the bleacher, and other similar trades.

But quantity must not alone be considered ; for the item of quality is of equal importance : and hence freedom from inorganic and organic matter should be sought after as much as possible. About twenty years ago we had occasion for a good supply of soft water ; and the locality was not of so much consideration as that condition. The result of our analysis of various streams and rivers was in favour of the water of the Lea, near London, and the Clyde, in Scotland. The water of the latter river is exceedingly soft ; that is, it is free from saline matters, especially lime. But, since that day, the enterprising citizens of Glasgow and Manchester have obtained the water, for all purposes, from much purer sources than had previously been known in any part of the kingdom. The Glasgow supply is next to rain-water in purity, and is obtained from a hill-lake—Loch Katrine—about forty miles from the city. It is also remarkably free from organic matter ; and hence is admirably adapted for every possible purpose to which it can be applied.

The chief cause of the hardness of water is the presence of lime salts, together with which the oxide of iron, soluble sulphates and chlorides, are also frequently present. All of these interfere, more or less, with dyeing processes ; and hence their detection, and, if possible, prevention, should be attempted as far as possible.

Accurate chemical analysis is not required to detect the nature of the solid substances present in water, as a qualitative examination is easily effected as follows, for all purposes of a practical nature.

Let several gallons of the water be boiled down till all is evaporated. A solid residue will be obtained, which will consist of the soluble and insoluble substances originally present.

About half a pint of distilled water, or, in its absence, clean rain-water, may then be added ; and heat should be applied. For this purpose it is best to transfer the solid matter, obtained as above, to a clean Florence or other glass flask, in which it can be readily heated with the distilled water. All substances soluble in water will then be removed, excepting the sulphate of lime, which is only soluble to a very slight extent. The contents of the flask should then be poured on to a filter made of bibulous paper : white blotting-paper answers extremely well. The clear liquid is to be received in a vessel placed beneath this filter, on the surface of which the solid insoluble matter will, of course, remain.

If a few drops of hydrochloric acid (or, as it is

technically called, the "spirits of salt" in the dye-house) be dropped on the solid residue, and it effervesces—that is, gives off gas—chalk or carbonate of lime must be most present, under all ordinary circumstances, in the water. If the filter be next put into a glass, and water with a little more acid be added, all the chalk will be removed. If any insoluble matter remain, it may be considered as sulphate of lime ; or, as it is more commonly called, plaster of Paris.

Now these rough results are very instructive. For example : if any of our readers are about entering on any of the businesses with which we have to deal in this chapter, they may thus easily examine the nature of the stream, or other source whence they expect to obtain their supply. It must be carefully borne in mind, that whilst both of these salts cause hard water, the *chalk may be got rid of;* but the sulphate of lime is *a permanent source of hardness*, for which we have as yet discovered no remedy: and this latter fact is of great consequenoe in determining the site for commencing new operations.

Generally speaking, it will be found that most sulphate of lime exists in waters that have percolated or flown over clay. The New River, that supplies water to the north of London, for example, contains sulphate of lime ; and if portions of the clay used for its banks be examined, together with that found adjacent to the banks, considerable quantities of crystals of the sulphate may be discovered.

On the other hand, chalk is abundant, in a soluble condition, in water that has flown over or percolated rocks or soil containing that substance; and hence it is frequently present in large quantities in Kent ; also in limestone countries ; as, for example, parts of Derbyshire, Yorkshire, &c., where, in the caverns, great masses of stalactites may be seen, that have been produced by the gradual deposition of the lime held in solution, from causes now to be described, and for which we can offer a remedy.

Whilst sulphate of lime is soluble in pure water, chalk, or the pure carbonate, is not; but, if any carbonic acid be present, the chalk readily dissolves. For example : if an ounce of lime-water be poured into a glass, and a *part* of a bottle of soda-water be poured on to it, instantly a white turbid appearance is produced, owing to the carbonic acid of the soda-water uniting with the lime of the lime-water, and forming chalk. Precisely the same operation occurs in nature. The air contains carbonic acid ; and this being gradually dissolved in water as it trickles over the chalk or limestone rock, dissolves the lime of the latter, and so forms a solution that renders the water *hard.*

If, however, such hard water be boiled, then the carbonic acid is driven off, and the lime settles down as a solid, of a yellowish tint ; and consists of common chalk, coloured, generally, by a little iron. Boiling may, therefore, be had recourse to for the purpose of rendering such water soft. But this leads to another evil, so commonly met with in steam-boilers—viz., the production of "fur," for the chalk lines the inside with a thick, hard coat, and soon causes the metal to be burned away beneath. Some years ago we had two thirty-horse power boilers, supplied by a well in Lambeth, the water of which was so hard that nearly a ton of this incrustation was removed monthly, in cleaning and chipping the boilers.

But a most ingenious method of testing water for chalk in solution, and of remedying the evil, was invented, some years ago, by Dr. Clark, of Aberdeen ; and the use of both depends on the principles already explained. The value of his method may be estimated from the fact, that the Commissioners of Woods and Forests require, before any bill for a fresh-water supply be submitted to parliament, "a statement of the quality of the water, as exhibited by chemical analysis, specifying its adaptation for domestic and manufacturing purposes, and its degree of hardness with reference to the tests and scale of Dr. Clark," must be submitted to them. And before fresh water-works are sanctioned by the Board of Health, it is required that the waters should be tested by the same means.

Clark's method of testing the hardness of water—and it must be here remembered that we only refer to the presence of dissolved chalk —is that of adding a solution of soap in spirits of wine to the water under examination. This soap solution is easily made by dissolving a piece of white curd or best yellow soap in an ounce of rectified spirit, aided by a gentle heat. A clear transparent solution is thus afforded. If such be added to pure rain or distilled water, no effect is produced ; but if a small portion only of chalk be present in the water, as is usually the case in all ordinary supplies, a milkiness is at once produced ; and the degree of this, compared with a standard solution of 16° of hardness, is the measure of the hardness of the water examined. A capital set of tests, apparatus, &c., for this purpose, may be purchased at most of the instrument-makers in the country, with full instructions for their use ; or can be readily obtained by them from the London makers of such articles.

After applying this test, the remedy is the next consideration ; and it is equally ingenious. The dyer or bleacher will know, that if he want to render his alkaline solutions caustic, he adds fresh-slaked lime. This seizes the carbonic acid of the carbonated alkali ; chalk is consequently formed, and the soda, or potass, thus acquires greater solvent or other properties, by being freed from the carbonic acid with which they were previously united. On precisely the same principle, if, according to Dr. Clark's plan, we add lime to water containing chalk dissolved by carbonic acid, the fresh-added lime seizes the excess of that acid, and falls down as chalk, together with that previously held in solution. Thus, the carbonate of lime, as the cause of the hardness of certain waters in chalk and limestone districts, may be removed.

Generally speaking, the waters of artesian wells—at least near London, and, of course, at all places where the surface-water has come into contact with chalk—contain that substance in solution. It is considered that, for brewing

purposes, such is beneficial than otherwise; but usually it is the reverse for the dyer. Even in the ordinary operation of boiling greens or peas its effect may be seen, for they are turned of a brownish colour, owing to its presence. Hence the use, by the cook, of a little "washing soda," which acts in precisely the same way as Dr. Clark's lime method; the alkali seizing the excess of carbonic acid, and precipitating the lime as chalk.

Referring our readers to p. 90, *ante*, we shall have yet to examine the soluble contents of the water; having now disposed of the lime it is supposed to contain, either as sulphate or carbonate. To examine these properly requires careful chemical analysis by competent persons; but a rough result may be obtained as follows.

Pour some of the solution into two wine or other glasses. To the liquid, in one, add a little solution of a few grains of nitrate of silver (lunar caustic), in distilled or rain-water. If a white powder or curdy substance be formed, that turns black on exposure to the light, some compound of chlorine must be present; as, for example, common salt (chloride of sodium), &c. If, on adding a little of a solution of chloride of barium to the contents of the other glass, a white powder falls, it shows that sulphuric acid (oil of vitriol) is present, united, most probably, with lime, soda, potass, and, in certain cases, with magnesia in the form, in this latter case, of what is commonly known as Epsom salts, that are constituted of sulphate of magnesia.

The preceding simple methods of arriving at a proximate knowledge of the constituents of any water, will be, doubtless, of much practical value. We have, however, only dealt with the alkaline, acid, and earthy constituents. We must now notice another source of impurity, of the utmost consequence in some technical processes. Two instances, in which we were consulted, will not only show the importance of ascertaining the possible presence of certain metals in solution, but may prevent the occurrence of much annoyance, not to say pecuniary loss.

In one case, a great quantity of broken jute and hemp, that had been treated with alkaline and acid solutions, was thrown into a large vessel of water for washing purposes. It was then transferred to a vat containing a solution of chloride of lime. After remaining some time, instead of being whitened, however, it attained a light-brown colour, that was not removable by any means that were tried.

On inquiry, we found that, instead of the ordinary and, comparatively, pure water-supply having been used for washing, the water had been drawn from a well on the premises. On analysis the water was found to contain much oxide of iron in solution; and hence, instead of the jute being bleached, it was actually *dyed*—the iron from the water, and the chlorine from the chloride of lime, having united to produce the colour just named.

In the other instance, a paper manufacturer found that his manufactured article was much complained of, on account of dull colour; what should have had a bluish tint being more of a dusky-brown in certain cases; but, generally, a dull tint prevailed. He drew his water-supply partly from a spring in an adjacent hill, but chiefly from a river that ran through his works; and, for a long time, it seemed impossible to account for the annoyance and loss of business that by some mysterious cause had arisen. We, however, proposed a trip towards the source of the stream; and, a few miles from his works, discovered that the washings of lead ore, after it was crushed, were habitually thrown into the river from which he drew his chief supply. In small quantities, the sulphide of lead, or lead pyrites, had become converted into a carbonate; and this, again, became dissolved, by excess of carbonic acid, in the water. This solution, at last, reached his mill, and, entering the pulp, became, from a variety of causes here unnecessary to state, converted into sulphide again; thus producing the brown tint that had injured the colour of his paper.

The relation of this incident brings to our mind another, that may act as a warning to many. A person with whom we were acquainted was largely engaged in the manufacture of a valuable colour; and, for reasons that we gave at a previous page, in reference to soft water, had chosen a stream that exactly suited his purpose. By an accident the "race" of a copper-mill became diverted, and the water cast against our friend's premises. In a few hours the effect became visible in the entire stoppage of the production of colour from the raw material used. In numerous cases the operations of dyeing are thus interfered with by a stream, whence the water-supply is drawn, becoming thus accidentally contaminated; and hence serious pecuniary loss may be caused until the source and remedy have been discovered.

In such cases the manufacturer should have instant recourse to a competent chemist, who should, as far as practicable, be instructed with all the facts of the case that can be ascertained; indeed, in a manner similar to that which would be followed in acquainting a physician with the symptoms of disease. The circumstances which we have related are generally exceptional, in so far as the presence of lead or copper is concerned; and we may, therefore, pass those two cases by. Iron, however, is a metal so universally distributed, and so commonly met with in well and other waters, that it is desirable we should give a few instructions for its discovery, leaving to more exact chemical analysis the duty of pointing out the quantity present.

In many parts of this country this metal is so largely present as to be deposited as a reddish-brown powder, by the water, as it flows into the open air. Such generally occurs in districts where iron ore abounds; but it is by no means universally the case. Take, for example, Hampstead Heath, to the north of London. It is constituted almost entirely of light-coloured sand and small quartz or felspar pebbles. But from them we have picked masses of concreted oxide of iron; and, on the east side of the heath, there is

a spring, so highly charged with iron in solution as to be an excellent chalybeate water, but extremely offensive to many, because of the quantity of metal in solution. It is impossible for us to select, throughout England, any place so unlikely as that to present so much iron; and, therefore, we may suppose that the possibility of the same frequently occurring is considerable.

If the solid residue obtained by boiling down water, as directed at p. 90, *ante*, be put into a flask, and heated with a few drops of *pure* nitric acid, diluted with *pure* water, and a little solution of the yellow prussiate of potass be added, if iron be present it will be soon evidenced through the production of a blue precipitate of Prussian blue. The quantity of this will, of course, indicate that of the iron present; and hence a rough estimate will be arrived at, which can be more correctly obtained only by proper and careful analysis.

A frequent source of trouble to the practical dyer and bleacher, arises from the pollution of streams by other means than those just described, especially by the flooding of streams after heavy rains. This results in the solution of many substances from the adjacent land, and in an increase of the suspended matter, both animal and vegetable. The first source of evil must necessarily be borne with, for it can only be remedied by waiting for its absence; the second may be easily cured by filtering through gravitation.

For this purpose two separate reservoirs are required, or, rather, one divided into two. The bottom, or bed, of both must be covered with sand and gravel, to a depth of several inches. A bank is now to be made by some stiff material—than which nothing is better than clay—so that the reservoir shall be divided into two, in such a manner as that the water from one-half can only reach the other half by percolating through the sand bottom. If one reservoir be filled with the turbid water of the stream, the other being left empty, the water will slowly find its way into the empty one, leaving behind it all its suspended impurity; and thus, under the worst circumstances, the dyer or bleacher may secure a constant supply of clear water.

By such means all the water supplied to London is thus filtered; and where formerly it had the appearance of a mixture of clay and water at certain periods of the year, the supply, at least on the north side, is now as clear as crystal during the whole year round.

It has been recently discovered that animal charcoal has not only the property of removing organic matter, when used as a filter for water, but even a large proportion of the inorganic impurities is also removed. In certain cases the result has equalled one-half, or 50 per cent. of the total quantity of the inorganic constituents of a water-supply thus taken away. We cannot, at present, estimate the value that such a discovery may assume; nor, in the present crude state of the experiments, can we rely on the results so obtained. Novelty always presents us with "facts" that have to be considerably reduced in importance as experience chastens our knowledge. Still, to Dr. Frankland, to whom we are indebted for this trial, great credit is due, as he was the first to suggest the use of this agent. It has long been employed for other purposes, as for the decolourisation of sugar, animal and vegetable matter generally; but, up to the present time, its uses in respect to the removal of inorganic substances, or even its power in that respect, were unknown.

It may be of practical value to many of our readers, to gather information in respect to the annual variation of the quality of water, arising from general, peculiar, and local causes. The following extracts from the report of analyses of Thames water, during recent years, may be taken as a type of all other rivers not affected by special circumstances—such as the occasional or periodical influx of mineral substances, the overflow, or freshets, of some streams, and other accidental conditions to which we need not specially refer.

"The fluctuations which take place in the quality of the water during the succeeding months of the year, are sufficiently marked to indicate the influence of the seasons. This may be seen from the following table, which exhibits the average composition of the water supplied by the Thames Companies, (that is, those which derive their supply at or about Thames Ditton, two miles beyond the limit of the tidal stream at Teddington) during each of the twelve months of the last two years:" and for years the average is pretty constant. The results are tabulated as follows:—

Months.	Total Solid Matter per Gallon.	Oxidisable Organic Matter.
	Grains.	Grains.
January	21·22	0·79
February	21·61	0·67
March	20·45	0·73
April	19·38	0·49
May	18·99	0·47
June	18·49	0·62
July	17·28	0·63
August	17·57	0·59
September	17·51	0·61
October	18·80	0·62
November	20·56	1·04
December	20·78	1·01

The inorganic matters, such as the sulphate and carbonate of lime, sulphates and chlorides generally, are included under the head of "Total Solid Matter per Gallon" of 70,000 grains—that is, ten pounds avoirdupois, of 7,000 grains per pound. The oxidisable matter is determined by the amount of permanganate of potass affected by it; the available oxygen of which is, to the organic matter, as one to eight; and the general results were controlled by the examination of the colour of the water when seen through a glass tube two feet in length, and two inches in diameter.

It will be observed, "that, from October to

February, the total amount of solid matter in the water gradually rises to its maximum, which is rather more than twenty-one grains per gallon; and then it as gradually declines, until, at the beginning of summer, it is no more than about seventeen grains per gallon. Throughout the months of July, August, and September it remains at nearly the same proportion; and then, with the advance of autumn, it slowly increases. The quantity of organic matter in the water is at its maximum in November, directly after the fall of autumn leaves; and its minimum is in the month of May. The same facts are observed with the water supplied by the New River, and the East London companies (both, more or less, derived from the Lea, of which we have already spoken), whose sources of supply are very nearly of the same quality as the Thames; but it is not so with the deep chalk water of the Kent Company," the water supplied by which, as we have already explained, is surcharged with carbonate of lime, or chalk; but otherwise comparatively pure.

The effects of the presence of organic matter on dye-materials, infusions, &c., &c., are often prejudicial, and might cause considerable loss. It must be remembered that there is always a tendency of such matter to produce decomposition by deoxidation; and hence, at all events, metallic solutions are open to such influences. For example, if we boil a solution of a copper salt with sugar, the organic matter, by the aid of heat, at once effects deoxidation. But the minutely-divided state of organic matter, as found in water as usually supplied, is far more favourable to such a result; and hence, although perhaps unperceived, many sources of loss arise to the dyer.

It has often been stated that we are deficient in brilliancy of colour, compared with the results of French dyeing; and some ridiculous assertions have been made in respect to the action of sunlight, the absence of smoke, &c., &c. It is far more than likely that the geological character of this country has most to do with this question, influencing, as it must do, the nature of the water which we are compelled to use for economic purposes. We have already pointed out that, in our households, hard water has a most prejudicial effect on the colour and digestive power of the vegetables cooked therein; and it does not require much science to extend the same facts in reference to its injuring colour imparted to fabrics.

Lastly, in respect to the chemical nature of water used in processes connected with dyeing, printing, and bleaching textile fabrics or yarns, we may point out that the heavens directly supply an article far purer than any which we can obtain on earth; that is, after the water has touched its surface. It is true that this supply is exceedingly uncertain; but, at the same time, it is highly valuable. Collected as it falls, rain-water is all but pure, provided that its fall has not been near towns; or, if so, that the wind has set in such a direction as to prevent the access of coal-smoke, which is usually charged with sulphur in the form of sulphuric acid; minute portions of arsenic; and ammonia, in the form of sulphate; with many other impurities. The solvent power of such water is great; and hence an economy of material may be greatly effected. It would be extremely desirable to ascertain some direct facts bearing on the differences which arise between obtaining a colour-extract by hard and soft, or rain-water. We have little doubt but that the result would stir up our dyers and others, especially colour-makers; the result of which, whilst flowing from a small centre of personal and pecuniary interest, would have the most beneficial effect on the community at large.

Chemical Principles of Dyeing.—Under this head we should find a large range of subjects if we undertook to explain every department of the arts of dyeing or bleaching. This will be done in detail when we deal with each individually. For the present we shall only enter into a short exposition of general principles.

If we dip a piece of calico, or, indeed, any other textile fabric into ink, dyeing does not take place; staining alone results from such an operation. In other words, the colour of the ink is merely temporary, and, to a great extent, may be washed away with water.

But ink is composed principally of two substances—namely, an oxide of iron (the sesquioxide), and tannin, or tannic acid. The former is derived from the copperas used in the manufacture of ink, and the latter from the galls. It is also largely contained in many other plants, and their products; as, for example, oak-bark, and the bark of many trees, sumach, &c.

If, therefore, we extend our experiment, and first soak the cloth in a solution of copperas (sulphate of iron), and, subsequently, expose it to the action of the air, by which, as we should say in science, the iron becomes more completely oxidised; if, after having so done, we dip the cloth into an infusion of galls, oak-bark, sumach, logwood, &c., we shall find that a black colour will be produced, similar to that of ink. But now it will be much more permanent; it will be evenly distributed over the cloth, and not appear patchy; and, by repeating each alternate step of the process, a real dyeing of the cloth may be effected.

The reason of this is as follows:—When the cloth is simply dipped into ink, it only receives *on its surface* the insoluble black matter of that liquid, which, from the fact of its being so insoluble, cannot penetrate the pores, &c., of the cloth. When, however, it is first dipped into the solution of copperas, the metal iron is present in a soluble state, and penetrates those pores. On exposing the cloth to the atmosphere, the iron is rendered, by the action of the oxygen of the air, insoluble; and, on its immersion in any of the vegetable infusions that we named as containing tannin, the iron seizes the latter, and continues with it, forming an insoluble black compound, and thus a comparatively permanent dye is afforded.

The iron is called a *mordant*, a term derived from the Latin *mordere*, to bite; because, at one time, it was supposed that it "bit" the colour

into or on the cloth ; and although the science of the question is fully understood, still the old term is universally retained.

The use of mordants is very ancient. Pliny, for example, writing about 2,000 years ago, in reference to the art of printing either cotton or linen cloth, as practised by the Egyptians, says—"Garments are painted in Egypt in a wonderful manner, the white cloths being first smeared, not with colours, but with drugs which absorb colour. These applications do not appear upon the cloths; but when these are immersed in a cauldron of a hot dyeing liquid, they are taken out, a moment after, painted. It is wonderful that, although the dyeing liquor is only of one colour, the garment is dyed of several colours, according to the different properties of the drugs that have been applied to the different parts. Nor can the dye be washed out."

It is evident, from the preceding quotation, that the use of mordants was fully understood even long before the period at which Pliny wrote ; for the art of dyeing had, in certain respects, arrived at great perfection in his day. Indeed, long before that period, the Syrian or Phœnician purple had enjoyed the highest reputation for its excellence as a brilliant and permanent colour. According to ancient accounts, it was derived from a species of mollusca, of the genus *Buccinum ;* but there, doubtless, existed many kinds of this dye ; and what little we know of it savours more of tradition than truth.

Generally we may consider every agent a *mordant* that permanently fixes a colour on a textile fabric, although the term is usually confined to such as relate to colour-products obtained from vegetable sources. Alum, and other salts of alumina, are most extensively used for this purpose ; and they generally precipitate the colour similarly to that found in its vegetable source. The same, to a certain extent, may be said of the chloride of tin, or, as it is better known, by the term "spirits" of that metal. Salts of lead and other metals have similar properties of rendering vegetable colours insoluble, and, therefore, of acting as mordants. In all these mordants we find what is called in chemistry, a "metallic oxide," a familiar example of the nature of which is seen in the rust of iron, which is an *oxide* of that metal ; in other words, the metal is united with oxygen, the vital portion of the atmosphere ; and thus, whilst its metallic character and properties are for the moment lost, new and valuable qualities are acquired by it and other metals similarly acted on.

A state of solution, as we have already seen, is essential to the action of a mordant ; because the pores, or tubes, of textile materials are too fine to admit insoluble matters. They are generally better dyed, for this reason, before spinning ; because then each fibre is more readily acted on, and is not subject to either tension or compression, as must result from the mechanical operations of twisting, doubling, or weaving ; hence the proverbial advantages in the manufacture of the best kind of woollen cloth, called "wood-dyed"—a practice never followed, however, in the case of cotton.

Much greater difficulty is found in making the action of mordants effectual with cotton than with silk and wool. This fact we have already noticed at a previous page. It may arise partly from the mechanical constitution of cotton fibre; but, as we have previously stated, the cause must also be chemical in its nature ; because, by the action of tannin, blood, oil, &c., the difficulty of dyeing that material is much lessened, and the permanency of the results more fully ensured. Great advantages would, doubtless, arise if extended experiments were made by a competent person on the reason of this difference ; and, certainly, pecuniary temptations are not absent to induce a patient and long-continued examination of the subject.

Opposed to the action of a mordant is that of a *resist*, the use of which is confined to printing. Its object is to prevent the dye from acting on that portion of the cloth to which it is applied ; and which, accordingly, comes out of the dye-bath of the original colour of the ground or basis colour ; or, if not, the colour that has been imparted is easily removed by various expedients, hereafter to be detailed. The action of a *discharge* is similar in purpose to a "resist," except that the colour is first given to the article, and then removed by some agent capable of effecting that result. Thus, if a piece of cotton be dyed black in the usual manner, and patterns of wood, as blocks, be applied to its surface, they being first coated with solution of tartaric or citric acid, wherever they touch the cloth it will become nearly white, because the acid removes the iron mordant that had previously given fixity to the colour. The ordinary domestic operation of removing ink-stains by means of "salts of sorrel," is of a precisely similar character, and is due to the free oxalic acid dissolving away the oxide of iron that forms the basis of the ink.

At present we merely deal with the chemical relations of such colours as are obtained from vegetable sources. The aniline dyes we shall treat separately ; but we may here notice some mineral substances that afford beautiful and permanent colours.

Prussian blue results from the decomposition of a solution of a salt of iron by the yellow prussiate of potass ; but, so far as our own experience has gone in the production of this pigment or dye in fabrics, in former times but little heed was paid to the dictates of chemical science. We quite well remember that a sudden rage set in for cotton dyed by the union of the salts just named; but the idea of per-oxidising the iron or the copperas (sulphate of iron) then employed, antecedent to the addition of the prussiate salt, was disregarded. (Our scientific readers will, of course, perceive that we are here referring to the ferrocyanide of potassium.)

It is by no means impossible that, even at the present day, a few suggestions as to the chemical principles involved in the production of the Prussian blue, especially on cotton, may not be without some value ; for, as yet, it is barely understood that the depth of the colour depends on the amount of oxidation that the iron undergoes. Precisely the same cause lies in

the production of a good black, when any solution of tannin, as from galls, sumach, logwood, &c., is employed with either copperas (the sulphate of iron) or the acetate of iron. Tannin gives no black precipitate with the protoxide or first oxide, but only when an additional amount of atmospheric oxygen has been communicated. For the same reason, in producing the blue colour arising from the use of copperas and prussiate of potass, the addition of a little fuming nitric acid, or of chlorate of potass and a mineral acid—such addition, in either case, affording an immediate supply of oxygen—is of great benefit, and as saving time, of much value to the dyer.

Another source of mineral colour may be noticed in the combination of a salt of lead with chromic acid, by which the most beautiful yellow and orange colours, of a permanent nature, may be produced. Indeed, the variety may be extended from a light lemon to a dark orange. So far as we have seen, except in large concerns, this source of yellow tints has been comparatively neglected in the ordinary process of dyeing. Many other combinations of metallic oxides or acids have similarly escaped the attention of those whose interests, we may suppose, are involved most especially in the utilisation of easily-obtained means of permanent colour-production. Dyeing, in fact, is yet far from being a complete chemical art.

The acids mostly in use are the sulphuric, or oil of vitriol, chiefly employed in dyeing for the purpose of dissolving indigo, and technically known as "oil of vitriol;" nitric acid, better known as "aquafortis;" and hydrochloric acid, or spirits of salts. The use of all these, however, is limited in general, as the liquids they are employed for the purpose of manufacturing, are often purchased, ready prepared, from the drysalters. Amongst "chemicals," are "spirits," or chloride of tin; "sugar," or acetate of lead; bichromate of potass; alum; acetate of iron, usually prepared impure, in a manner hereafter to be described; with others, which will be also duly noticed.

Vegetable Colouring Matter.—We may next turn to the plants and their products, whence vegetable colouring matter is obtained; and here we may observe, that much has yet to be learned even from the highest branches of chemistry. What are called "vegetable principles," are, at present, but little understood. Our first view of these matters has been necessarily gathered from the study of the alkaloids; and these have, *incidentally*, led to the consideration of what were formerly aggregated under the term "extractive principles." For example, if we take safflower, we find it to have been discovered that a substance called *Carthamin* has been derived, or "extracted," from it. Indigo leads us into a still greater difficulty, the end of which is only found in a study of what we now term aniline colours," the analogues of which it will be our business, hereafter, to point out. In the same manner we may instance madder, from which "garancine" and "alizarine" have been extracted. It is impossible, in the present state of chemical science, to predicate what further discoveries may be made; but we venture to anticipate that, in every case in which a colour has been obtained from vegetable sources, we shall find what we *now* call a *principle*, will, eventually, obtain a term more consistent with scientific precision of language. Improvements, like knowledge, progress but slowly.

We may, therefore, recommend to those who wish to become practically acquainted with the science of dyeing, a careful and patient study of the principles to which we have referred. For the plan we are indebted to Davy, who suggested great improvements in the art of tanning. He was the first to point out the essentials required to extend that important branch of manufactures; and a similar field is open to that experimentalist who will lead the way in the direction we have ventured to suggest.

Practically, however, the dyer need not trouble himself in this respect. Fortunately the price of most dye-stuffs is exceedingly low; and, as a rule, no person is "better paid" than he who adopts the art of dyeing as a trade. We do not here refer to the "operatives" in that line of business; for, together with bleachers, paper-makers, and the manufacturers of chemical substances on the large scale, few persons have to undergo, in any branch of business, so many and constant changes of temperature, and, consequently, greater physical hardships than even the hard-working "navvy," who so greatly aids in the construction of our railway and other public works.

The action of extraneous agents is a matter of great importance to the dyer, in reference to the production of brilliant and permanent colours from the various vegetable sources to which he is compelled to have recourse. At a previous page (see *ante*, p. 90), we have pointed out how impure and partially saline water may affect his operations; and we have little hesitation in saying, that the success of a large establishment must greatly depend on particular attention to this point. The constitution of vegetable colours is very delicate, not only in a chemical, but in a practical point of view. Of course, as chemists, we regard results in respect to quantities; but even thus, the increase of weight, from the use of a dye-stuff, is comparatively small. A ten-pound bundle of cotton yarn is but triflingly increased on being dyed of a rose colour from safflower; but the quantity of water used in that operation is very great. Hence the neutralising power of any carbonate of lime or chalk present, may have a very great effect on the brilliancy of colour produced.

It is well known that a small portion of acid vapour in the atmosphere will speedily turn "colours," dyed from litmus and other lichen substances, of a "foxy" red; restorable, however, to the original colour by ammoniacal fumes, simply because the atmospheric acid vapours are thus neutralised. Litmus is thus a most essential test in our laboratories, as a detecter of acid presence; and the dyer much employs it with

cudbear, &c., for producing various lilac and cognate tints, especially on silks. Turmeric has naturally a yellow colour, and gives the same class of dye. But if a free alkali be present, that yellow becomes a deep brown, for which reason is the laboratory use of an infusion or tincture of turmeric, in detecting caustic potass, soda, ammonia, magnesia, lime, baryta, and strontia.

Thus, whatever the natural character of the infusion or decoction of a plant, or its parts, may be, we must look for certain modified results in its ordinary treatment as a dye-stuff; that is, when it is put into use as a bath. A further consideration of these facts would lead us back again to the exposition of the effects of mordants; for whatever fixes a colour, exterior or extraneous to the colouring matter employed, may be regarded in that light.

Having suggested, however, the wide field that is still open for original investigation in reference to the colouring principle of plants, and limiting ourselves in using that expression to its popular sense, we proceed to give a botanical and chemical description of some of the leading plants and their products, of ordinary use in the dye-house; reserving for our future pages an account of the separate treatment of each for the purposes of the dyer. In so doing we shall (at least we hope to do) present some new, or rather previously unknown facts for the consideration of many of our readers. Nothing is more advantageous for the progress of an art than a broad foundation. We do not boast of laying this further than our personal knowledge will permit.

As we shall hereafter aggregate those materials that produce a specified colour, it will by no means be prejudicial to our plan if we give a detailed account of the leading sources of vegetable colours in an alphabetical order. Those of our readers who are desirous of seeing specimens of the different materials we shall describe, and are not connected with the arts that we are now describing, may have their curiosity gratified, generally, at the Museum of Economic Botany, at Kew, near London.

Taking dye-stuffs of chief use in alphabetical order, they are as follow:—

Alder.—The bark of this tree, which is exceedingly common in England, and other temperate countries, has a double use in dyeing and tanning. For the former purpose, it produces, according to treatment, a colour varying from yellow to an orange. As it contains a certain amount of tannin, it affords a black colour with an iron mordant; as, for example, the sulphate or acetate of iron. Its uses, however, for any of the purposes to which we have referred are limited, because, despite of its comparative cheapness, its bulk renders it somewhat cumbersome. Botanically it belongs to the Beech order, *Betulaceæ*, and it is known as the *Alnus glutinosa.*

Alkanet Root.—The root of the *Anchusa tinctoria*, of the order *Boraginaceæ*, and a native of the shores of the Mediterranean, has long been known as a source of a red colour; but it is little used in dyeing, because it requires either oil or spirits for the extraction of its colours. Its employment is chiefly confined to the colouring of ointments, lip-salves, &c.; although, occasionally, it is used, fraudulently, to give colour to "port wine."

Aloes.—The extract familiarly known under this name, is derived from various species or varieties of the Aloe genus. It belongs to the Lily order (*Liliaceæ*), and is a native of tropical climates. The leaves of the Socotrine aloe (*Aloë socotrina*) afford a rich violet colour, not requiring a mordant to fix it; and other species, by proper treatment, give a brown dye. It is more than probable that this extract may become a valuable source of colours, varying from an orange to a brown. It is, however, from its high price, but little, if at all, used.

Arnotto, or *Arnatto*, is obtained from the pulp that covers the seeds of the plant, botanically known as the *Bixa orellana*, and of the order *Flacourtiaceæ.* It is a native of South America, and affords a yellow or orange dye for silk; but is chiefly used to colour cheese and butter; and, occasionally, for the same purpose in varnishes. The colour is rich, and, if carefully managed, even brilliant.

Barberry.—The Barberry plant (*Berberidaceæ*) is a native of this and other temperate climates, and is familiarly known as a shrub in our hedges. The stem, root, &c., give a yellow dye with a proper mordant (alum); with other mordants, a black may be obtained; and, from the presence of tannin, the various woody parts may be used for tanning purposes.

Barwood, or *Camwood*, are terms indifferently applied to the chips, as imported, of the stems of the *Baphia nitida*, a West African tree. It belongs to the *Leguminosæ*, or Peaflower order, distinguished by bearing pods or fruit like our peas and beans. But this kind is embraced in a different section, called *Cæsalpinieæ* by naturalists, which include logwood, and several other trees, with their products, employed in various branches of the art. Camwood gives a very excellent red dye, used in producing that colour on Bandanna handkerchiefs. Sappanwood is also included in the botanical section and order; and its uses for wool-dyeing are extensive. It is imported from Ceylon and India.

Bedstraw, the *Galium verum*, of the same order botanically as madder (*Rubiaceæ*), is a native of Europe, and pretty widely distributed. In many respects it may be considered a valuable material, although it is, comparatively speaking, but little used, because other sources exist from which the same colour may be more readily obtained. Its flower yields a yellow dye with an alum mordant; and the roots are not much inferior in affording a red colouring matter when compared with madder.

Brazil-wood, like Barwood or Camwood, belongs to the Peaflower, or *Leguminosæ* order; is a native of the Brazils and West Indies generally, and a very common source of bright-red dyes; and is a basis for the manufacture of red

ink. It is chiefly used in the form of "chips," being imported in the "log," or stem form. The inner portion of the stem is that which affords most colour.

Broom.—This plant is well known in most temperate countries of Europe, and is frequently an ornament of our garden. It is familiarly known, at least the species to which we refer, as "dyer's weed" *(Genista tinctoria)*, *Cytisus scoparius*, or *Sarothamnus scoparius*. It affords a yellow dye; and, containing tannin, may be used in the conversion of skins into leather. It belongs to the *Leguminosæ*, or Peaflower order; but to the section of the *Papilionaceæ*, or that whose flowers, in their development, resemble the shape of the wings of the butterfly.

Buckthorn.—Under this head many vegetable dye-products may be included. The whole are embraced in the genus *Rhamnus*, and natural order *Rhamnaceæ*. They are natives of Europe, Middle Asia, &c. As a rule, the dye-products are of a yellow colour. French, Avignon, or yellow berries, Persian, Spanish, and Turkey berries, have all their source from this genus. The berries of the *Rhamnus catharticus*, used in medicine, afford "sap-green," by the action of lime; whilst the bark of the same species gives a yellow dye. Morocco leather is dyed of a yellow colour by use of the Persian berries, or the "dyer's buckthorn," or *Rhamnus infectorius*, which also affords a bright yellow dye from the unripe berry, and is used in printing calicoes.

Campeachy-wood we shall notice under the nead of *Logwood;* and *Camwood* has been already noticed as *Barwood.*

Catechu is prepared by boiling the heart-wood and pods of of the *Acacia catechu*, a native of the East Indies, and belonging to the botanical order *Leguminosæ;* sub-order, *Mimosæ*. It is chiefly used for its tanning properties; and is, therefore, capable of affording a black dye with an iron mordant. It is also known by the name of *Cutch*, and *Terra japonica*, in the quotations of our drysaltery markets, although the latter substance has an entirely different origin. As imported into this country it is a kind of resinous extract.

Chica, the product of the *Bignonia chica*, order *Bignoniaceæ*, is a native of South America, comparatively little known in this country. By the Indians of the Orinoco river, it is employed as a paint for ornamenting their bodies; and it affords an orange-red to cotton yarns and goods.

Cochineal.—This, of course, cannot be called a vegetable dye; but, chemically, we may consider the colour as resulting from an assimilation of a plant production; the insect from which the dye is obtained feeding on a species of cactus, the *Cactus opuntia*, or Indian fig, a native of Mexico, Central America, and Brazil. It is astonishing how important so small an object as the cochineal insect becomes; but some idea of it may be gained when we state, that, whilst 70,000 of the insects weigh but one pound, about 35,000 cwt. are annually imported into this country for dyeing purposes. The *Coccinæ* are hemipterous insects; the most important of which is the *Coccus cacti*, a name applied to the original species of Mexico, where, for a long time, its cultivation was exclusively confined. It has, however, of recent years, been spread over a wide area, and extended even to Spain and Algiers. The *Lac insect*, to which we are indebted for lac dyes, shell lac, &c., belongs to the same family. It is an inhabitant of the East Indies; and is known in natural history as the *Coccus lacca*. It feeds much on the banian tree, or *Ficus religiosa*. The *Kermes*, or *Coccus ilicis*, feeds on a species of oak, the *Quercus coccifera*, and is a native of Southern Europe. Like the rest of its tribe, it affords a red dye; but is now quite superseded by the true *Coccus*, or cochineal insect. Of all the insect tribe, these are of greatest commercial importance; and their use, for dyeing purposes, may be traced back even by thousands of years; for the ancient Greeks and Romans thus used some species. The annexed cut (Fig. 82) illustrates the ap-

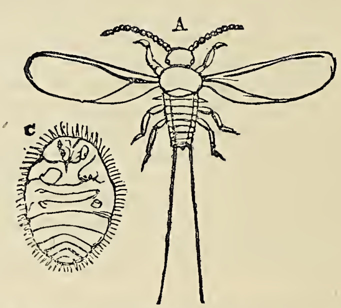


Fig. 82.—Cochineal Insect (*Coccus cacti*). A, male; C, female.

pearance of the male and female of the cochineal, or *Coccus cacti*. The female insect alone yields the commercial products to which we have drawn attention.

Crottel and *Cudbear* may be properly classed with other lichens, for to this family they all belong. Crottel, or, as it is termed in botanical science, *Parmelia omphalodes*, is a native of Europe. It grows on the stems of trees, and on the *débris* of rocks. It affords a brown colour with the sulphate of iron or copperas; and is used with sumach and logwood. Cudbear is the product of various species of *Lecanora*, that grow on rocks, at high elevations, in cool climates. It affords a purple or mauve colour to woollen goods, but is fugitive; and is extracted by the action of ammonia, chiefly obtained from stale urine. Litmus is also procured in a similar manner from other species of *Lecanora*. It is commercially known by the name of archil, or orchil; and is used to give various shades of purple to silks. Like all lichen dyes it is fugitive.

Fustet will be described under the head of Sumach.

Fustic affords a yellow dye. Although confounded in name with sumach, it is an entirely different article. It is procured from various species of the mulberry tribe, or *Moraceæ*, as the

Maclura tinctoria, or *Morus tinctoria*, and is a native of the West Indies, Brazil, &c.

Galls are of great use in dyeing, ink-making, &c., and result from the puncture of an insect on the leaves of the *Quercus infectoria*, a native of Asia Minor. The female inserts its ovipositor in leaves, buds, &c., depositing an egg in the wound. This causes, together with the action of an irritating fluid, a diseased growth of the part. This portion gradually enlarges, and forms a round ball, in the centre of which the larva lives until it has attained its full growth. In this condition it appears like a white maggot. After undergoing its transformation, it eats its way out, leaving a minute hole, by which it has escaped. There are several species of the insect. That which produces the oak-apples of our country is the *Cynips terminalis*. Another species, the *C. Quercus-folii*, is represented in the annexed cut. It chiefly attacks the leaves of

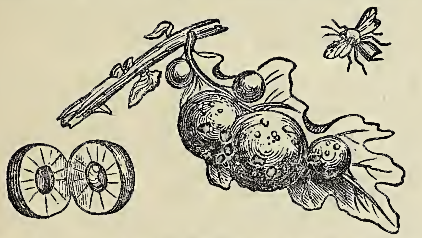


Fig. 83.—Galls of Oak-leaf, and Insect (*Cynips Quercus folii*).

the oak, producing small galls, also represented in the cut. The commercial galls are produced by a species known as the *Cynips Gallæ tinctoriæ*, and is illustrated, with the gall itself, in Fig.84.

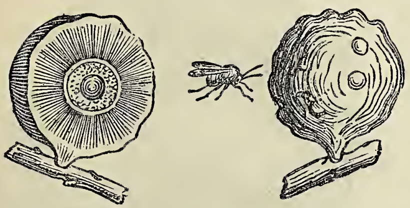


Fig. 84.—The Commercial Gall, and its Insect (*Cynips Gallæ tinctoriæ*).

It is remarkable thus to find that some of the most important and valuable substances used in dyeing—as, for example, cochineal, lac, kermes, and galls—are either insects, or due to insect production. The value of the gall depends on its containing astringent or tannin matter; hence its employment with a mordant in dyeing silks, &c.; and with copperas, or sulphate of iron, in the manufacture of ink.

Gambir, or *Terra japonica*, much resembles catechu. It is the production of the *Uncaria gambir*, a native of the East Indies and the Malay islands. It is highly astringent, containing tannin; and hence is much used both in dyeing and tanning. It contains a principle called *catechine*.

Garancine will be described in connection with madder, of which it is the active colouring principle.

Heath.—Some species of the heath tribe, or *Ericaceæ*, are used in tanning, on account of their containing astringent matter. The common heather of our moors, the *Calluna vulgaris*, affords a yellow dye when used with an alum mordant.

Henna.—This plant, the *Lawsonia inermis*, a native of Africa and Arabia, is largely used by Egyptian women to give an orange colour to the nails. The powdered leaves are used to dye leather of a reddish yellow or orange colour: it seems to have a strong affinity, as a dye, for animal matter.

Indigo.—This article has long been of great importance to the dyer in producing fast blue colours. It is produced from various species of pod-bearing plants, or *Leguminosæ*; sub-order, *Papilionaceæ*; of the tribe *Indigofera*; and natives of India, Africa, and America, in hot climates. For commercial purposes two or three species are chiefly had recourse to—namely, the *I. anil*, *I. tinctoria*, and *I. argentea*. The colour is obtained from the leaves, but does not exist in them as a blue substance. These are picked when just at bloom; as, at that time, they yield the largest quantity of indigo. On being put into a vat with water, they are beaten, and allowed to undergo fermentation. The liquor is then run off into another vat, and kept for some time in constant agitation, so that air may have abundant access. The oxygen of the atmosphere thus combines with the indigo matter, and changes it to a blue and purple colour. The liquor is then allowed to settle, and gradually the indigo itself is precipitated to the bottom of the vessel. It is subsequently removed and heated; then the water is filtered off, and the colouring matter remains as a consistent mass. This is submitted to pressure, dried, and cut up into small cakes, in which condition it is exported.

There are many interesting chemical and practical questions relating to indigo, some of which we may briefly notice.

It is first to be remarked, chemically, that it is formed in two states: the white, which is destitute of colour, and the blue, which results from the white kind having become oxidised; that is, united with oxygen, the vital portion of acid. In the blue condition it is quite insoluble in water; and hence, in that form, with a reservation we shall presently notice, is absolutely useless to the dyer; but by *deoxidising* it—that is, removing the oxygen which has altered it from the white condition—and thus, by restoring the blue to the white condition, it becomes soluble. For the present, we may state that this is effected by the agency of copperas, lime, and water. The copperas, or, as it is termed in chemistry, the protosulphate of iron, has a great affinity for oxygen; and thus, when the indigo and lime are all mixed with water, the iron of the copperas attacks the oxygen of the blue indigo, and decomposes it, setting the white kind free, which *is* soluble in water. A liquor is thus formed, in which the latter is in solution; and, if goods be

dipped into it, they absorb the soluble colouring matter. But at first they have no colour. On being exposed, however, to the action of the oxygen in the air, the white indigo again absorbs that gas, and gradually becomes blue; when, of course, the goods simultaneously assume that colour.

We stated that there is another method of rendering indigo soluble, and so available for the dyer's use. This is done by dissolving it in sulphuric acid, or oil of vitriol.

The chemical relations of indigo, apart from its practical employment, we have stated to be exceedingly interesting. By a heat of about 550° it may be readily sublimed, forming a vapour of a violet colour. On reaching a cool surface it again becomes solid, in the form of fine needle-shaped crystals. If boiled with caustic potass (pure pearlash), it produces a compound called *aniline*, which, as we shall afterwards describe, is obtained from the tar-liquor, produced by the distillation of coals in the ordinary way of gas-making—a result that has been of the utmost importance in the art of dyeing, and, indeed, has completely revolutionised it; hence what are called aniline colours, now so extensively used to produce mauve, rose, Solferino, Magenta, and other rich dyes, to which we propose hereafter to devote a separate and extended notice. From indigo, acted on by nitric acid, another, called *Picric acid*, is produced; now, however, obtained from the aniline of coal-tar liquor, and used as a yellow dyeing agent. Besides these results of chemical action on indigo, there are many others; but, as they are more of scientific than practical interest, we shall, for the present at least, pass them by.

The indigo of commerce varies greatly in value, a matter of much importance to the dyer. Generally it may be judged by its colour, which should be of a deep violet. If rubbed by the back of the finger-nail, it assumes a copper-like hue. Numerous methods have been proposed to test its pecuniary value; but it must be remembered that, in one "parcel," if examined chemically, it would be impossible to acquire accurate results, because each cake might vary in quality. Now chemical analysis can only deal with a very small portion—a few grains—of each cake. No dependence, therefore, could be placed on any result so obtained, as a test of the quality of the whole parcel. We cannot, after perusing the many plans of thus attempting to arrive at the commercial value of a sample, recommend any one to the practical man. In fact, in this matter, as in agricultural chemistry, when we attempt to judge of the qualities of the soil of a field, or an estate, we are at once met with the common difficulty of uniformity in collecting specimens. Long experience alone can guide the dyer, therefore, in his purchases of indigo, aided by the commercial character for integrity of the person from whom he buys the article.

The preparation of the chemic, or blue vat, will come under notice when we enter into the detailed and practical portion of our subject. We now return to a description of the various remaining plants, and their products, of use in dyeing.

Kermes we have already spoken of, as an insect belonging to the cochineal kind. It was formerly much used as a source of red dye, but is now entirely replaced by the cochineal.

Kino is an astringent substance, containing tannin; and hence is of great value for tanning purposes. For this reason it affords a black with an iron mordant. Numerous sources of it exist. Species of *Pterocarpus*, belonging to the pod-bearing, or *Leguminosæ* order, are natives of the East Indies; and the extract is there used to dye cotton of a yellow colour. Some of the gum trees, or *Eucalypti* of Australia, yield a resinous astringent matter, also known as kino; and this source will, doubtless, become both plentiful and valuable. No arts have benefited so much by chemistry as have dyeing and tanning; for an application of its principles, as previously remarked, has not only enormously increased our sources of material, but has simultaneously afforded us a great variety of new processes.

Lac Dyes.—The sources of these have been already noticed in connection with the cochineal insect, as resulting from the puncturing by a species of *Coccus* on the banian tree and others, natives of the East Indies.

Lichen Dyes.—The chief of these, such as litmus, or orchil, cudbear, crottel, &c., have been described in connection with the two latter.

Logwood.—This wood, also called Campeachy-wood, is of extensive uses in dyeing. It is obtained from species of the pod-bearers, or *Leguminosæ*—a most fruitful source of dye-stuffs,

Fig. 85.—The Logwood Tree.

as we have already seen in their previous enumeration. It belongs to the sub-order *Cæsalpinieæ*, and is a native of Central America, &c. The preceding cut (Fig.85) represents it as growing in its native country. The stem is sawn into short pieces, the bark removed, and, after being imported, it is broken into small chips, in which condition it is ready for the dyer's use. With different mordants it affords reds, purple, slate, and blue-black, for the last of which it is greatly employed. It contains a principle called *Hematoxylin*, to which its red colour is due. The botanical name of the tree is *Hematoxylon campeachianum.* Allied to this is Peach or Nicaragua-wood, the *Cæsalpinia Brasiliensis* of the same order and sub-order, and a native of South America. With proper mordants it affords various tints of red colour.

Madder.—This root is one of the most valuable that the dyer employs. It is obtained from the *Rubia tinctoria*, order *Rubiaceæ*, and a native of France and the south of Europe. It is a perennial plant; but the root is not used until the second or third year of its growth. After being dried and ground, it is ready for the dyer, by whom it was formerly much employed in this condition. By aid of chemistry, however, its active colouring principle is now extracted. This is done by acting on the powdered root by sulphuric acid, when *Garancine* is afforded. This proximate principle, however, contains two others; and to one of these, *Alizarine*, the colouring power is chiefly due. With it is associated *Purpurin;* and both of them, by chemical means, may be obtained in the form of bright-red crystals. The great employment of madder is that of Turkey-red dyeing. Within the last few years *Alizarine* has been artificially produced from a product of coal distillation.

A variety of madder, called *Munjeet*, obtained from the *Rubia cordifolia*, is employed in India (in the north of which it is native), in a similar manner to the madder of Europe; which it resembles in its colouring properties, and in affording the principle garancine, just described.

Myrobalans is the fruit of an Indian tree: it contains much astringent principle, and is, accordingly, largely used in tanning; but, from the same property, would of course produce a black with an iron mordant.

Oak Bark—This is too well known to require description; and the remarks just made in reference to myrobalans, are equally applicable to it.

Orchil, or *Archil*, has been already described in connection with *Crottel*, *Cudbear*, and other lichen dyes.

Peach, or *Nicaragua-wood*, has been similarly treated, together with *Logwood.*

Persian Berries have been included with the description of *Buckthorn.*

Pomegranate Bark.—The pomegranate has long been cultivated for its fruit, and is mentioned from early times in all history. It is considered to have been originally a native of Western Asia, between the Levant coast and Persia. The name, *Malum punicum*, refers to Carthage; and hence has arisen the opinion that there it was first known. It belongs to the *Myrtaceæ*, or Myrtle order. The bark is used in dyeing.

Rhubarb stalks are now largely used as a source of red dyes for wool, etc.

Quercitron has long been known as a good yellow dye-stuff. The tree is a native of North America, and belongs to the oak tribe, being known as the *Quercus tinctoria.* The bark is the portion used for dyeing purposes. It also contains tannin; and, therefore, with an iron mordant would afford a black colour.

Safflower.—Until the comparatively recent discovery of the aniline series of colours, safflower was the chief source of rose-red dyes, especially for silk; and even now it is largely employed. It is the flower of *Carthamus tinctorius*, a plant of the Composite order, flourishing in China, India, and the south of Europe. It is composed of two colouring matters—the yellow, which is by far the most abundant; and the red, which, although the only one of value, is contained in very small quantities. It arrives in this country in packages or bales, the flower presenting a dull-red colour. In the first place it is washed abundantly in a porous bag with cold water, to set free all the yellow matter, which is readily soluble. A dull reddish mass is thus left. To obtain the red colouring matter, this residuum is soaked in a solution of carbonate of soda, which, however, apparently produces no result. But on adding lemon-juice to this solution, a rose-coloured tint is at once produced. The usual method is to employ cotton for the purpose of absorbing the colour. It is dipped in the alkaline solution, pressed, and then immersed in a solution of citric or tartaric acid, or lemon-juice The colour instantly strikes on the cotton a beautiful rose-red; and the process is repeated continuously until the cotton is saturated with the colour. The latter is then removed by carbonate of soda, and precipitated by lemon-juice or citric acid. In this form it is sold as a red thickish liquor, for dyeing silks, &c., of a rich rose colour, unsurpassed by any other dye-stuff. Some years ago we made a great number of experiments, in the hope of rendering this colour permanent; and, to some extent, succeeded so far as the action of air and moisture were concerned. But we entirely failed to render it unaffected by alkalies and soap, which turned cotton dyed with it to a rich peach colour. The red colouring matter, or principle, is recognised by chemists as *Carthamin.* This, precipitated as a comparatively insoluble matter, forms a kind of carmine, and is the cause of colour of the red saucers, formerly employed for domestic dyeing. At the present time, one of the aniline colours is much used, in place of safflower, for some tints of a rose-red.

Saffron.—This was formerly in request as a yellow dye; and, at one time, the plant was much cultivated in Essex; hence the name of the town of Saffron-Walden. The saffron of commerce consists of the dried stigmas, or tops of the central organ of the flower of the *Crocus sativus.* Its use in dyeing is very limited; but, as a colouring material, it has many applications.

Sanders-wood (red), *Saunders-wood*, and *Santal-wood* are terms applied to a material obtained from the *Pterocarpus santalinus*, of the prolific order for dyes, *Leguminosæ*, and sub-order *Papilionaceæ*. It is a native of India; and affords a red-brown dye for woollen goods, and red or scarlet with some mordants. *Sappan-wood* belongs also to the *Leguminosæ*; but is separated naturally from the preceding on account of its affinity to *Cæsalpinieæ*. It is a native of India, Ceylon, &c., and is much used as a red dye-stuff.

Sap Green and *Spanish Berries* have already been described in connection with Buckthorn, at p. 97, *ante*.

Sumac, or *Sumach*, has come largely into use of late years, in dyeing and tanning, because it contains much astringent matter, and is, therefore, highly suitable for producing a black with an iron mordant. It also gives an orange-yellow if properly mordanted. The leaves and the twigs of the *Rhus cotinus* and *coriaria*, of the order *Anacardiaceæ*, and a native of Southern Europe, produced it. Sometimes the names of *Young Fustic* and *Fustet* are applied to it. The large amount of tannin that it produces is not valuable, simply for the purpose already named; for it has the property of preparing cotton to receive other dyes, *apparently* imparting to it a nature somewhat akin to that of an animal substance. It has also the property of adding much to the weight of silk; and is taken advantage of in what is technically termed the weighting of that article.

Another use of sumach we may just mention, as, although amusing, it is not without some beneficial quality. Having, during one of the so-called "cholera years," two or three large tanks of water, constantly preparing "baths" of sumach for dyeing, it occurred to one of the men (after a rough hint we threw out one evening) to use a little in place of his "tea;" for there is much similarity between the taste and smell of the infusion of each. A joke soon became practical as a habit; and to a constant use of this kind of "tea" we have always ascribed immunity from cholera and diarrhœa attacks amongst a large number of men living and working in a neighbourhood in which these diseases, at that period (1849-'50), were more fatal than in any other part of the country.

Tannin, as a separate material, is of course, from its great expense, never individually used in dyeing. We have already noticed it, however, as a constituent of oak-bark, galls, logwood, kino, myrobalans, sumach, &c., all of which are, or may be, used with an iron mordant in dyeing black. It has been also just mentioned that tannin may be used to give cotton a power of retaining colours that it does not otherwise possess, and which is frequently had recourse to in preparing for certain dyeing processes. The tannin extracted from the substances already named, and from many other, is characterised by the property of precipitating gelatine as an insoluble substance; hence the use of such material in converting hides or skins into leather, which is, in fact, simply gelatine thus solidified. There is no doubt that tannin is a very widely diffused principle in plants, and especially such as are used for dyeing purposes. A large portion of those that we have enumerated are known to possess it in very large quantities; and there is considerable reason to suppose that its presence may have much to do with their dyeing qualities, or rather the power of attaching themselves to certain textile substances. We are much indebted to Sir Humphry Davy for extended researches on this subject; but, since his day, our sources of tannin have been greatly increased. It may be obtained in a tolerably pure state, as tannic acid, from powdered nut-galls, by the action of ether. This is done by placing the powdered galls in a funnel, the stem of which should rest in a narrow-necked bottle. Ether is allowed gently to penetrate through the mass, and, after a time, the gallic and tannic acids will both be dissolved out. But the former is barely soluble in water; whilst the tannic acid is readily soluble in that liquid. Consequently the tannic acid will be found united with any watery fluid drawn from the ether at the lower part of the glass bottle. It possesses the property of giving a blue-black with the sesquioxide of iron; and hence the necessity of exposing goods dyed with copperas to the action of atmospheric air, so that they may absorb oxygen, and thus convert the protoxide of that salt into a higher or sesquioxide condition. Gallic acid similarly affords a blue-black colour with the sesquioxide and persalts of iron; but none with the protoxide. By a lengthened exposure of powdered galls to the free action of air and moisture, the tannic acid is converted into the gallic, when it is obtained in beautiful white silky needles. It is the presence of both these acids in bark, galls, and other astringents that we have named, which gives them their value for producing black colours for the dyer's use.

Terra Japonica has been already described as *Gambir*. It is used because of its containing tannin, both for tanning and dyeing purposes. It is sometimes called *Catechu*; but, as we have already explained, that extract is derived from an entirely different source.

Tobacco.—This plant needs no explanation of its ordinary uses, as for smoking, &c. It belongs to the order *Solanaceæ*, and forms various species of the genus *Nicotiana*. Its leaves are said to afford colouring matter.

Turkey Berries have been already noticed in connection with other berries produced by the Buckthorn family.

Turmeric, also called Indian Saffron, has long been used as a source of yellow and orange dye. It is produced from a plant of the Ginger family, or order, the *Zingiberaceæ*, and is commonly cultivated in India and China, where it is much used in cookery as an aromatic condiment for curries, and other Indian dishes; the root being thus employed, and in dyeing, in a powdered state. The plant is represented in Fig. 86. By the action of soda and potass it is turned to a permanent brown colour, as is also a bath made from it; but, if ammonia be employed, the effect

is transient, and disappears as the alkali passes off as gas. Paper stained with its tincture, or

Fig. 86.—The Turmeric Plant.

infusion, is therefore used in the chemist's laboratory as a test for alkalies in a free or caustic condition.

Valonia is a valuable material in tanning and dyeing, from its possessing so much astringent or tannin matter. It consists of the acorn-cups of a species of oak, the *Quercus Ægilops*, a native of Greece and Asia Minor, from which countries it has, of recent years, been largely imported, to the extent of many thousand tons annually.

Walnut-peels—that is, the external coat, or husk of the nut—are used in dyeing brown, &c. The fruit is well known as a dessert and a pickle. The English species is the *Juglans regia;* but there are several others, forming the order *Juglandaceæ.* The wood is greatly valued for its ornamental qualities, as a material for cabinet ware; but has no use in dyeing.

Weld.—The leaf and stem of the *Reseda luteola*, a native of this and other temperate countries, afford a good yellow dye, and was much employed for that purpose. It requires working with alum and tartar, however, to give a permanent colour. The whole of the plant is available for dyeing purposes.

Woad we may call the British indigo, because, for centuries, it has been used in this country as a dye-stuff; and prior to the invasion of Britain by the Romans, was used by our savage ancestors to dye their bodies of a blue colour, in place of what they did without—decent garments. Its extensive and ancient use in other nations of Northern Europe, is evidenced by the similarity of name applied to it in each of the different countries where it is common. The colouring matter is derived from the woad plant, or *Isatis tinctoria*, belonging to the order *Cruciferæ*, embracing cabbages, wallflowers, and many other plants, distinguishable by the cross-like form of the four flower-leaves. A portion of the stem-leaves, &c., is represented in Fig. 87. Formerly

Fig. 87.—The Woad Plant.

it was extensively used in place of indigo; and was the chief, or, perhaps, only source of permanent blue colours. When indigo was first introduced into Europe, it was added in but small portions to woad. Eventually, however, its superiority became apparent; and the quantity used was gradually increased until the woad became but a small portion of the dye-stuff. Owing to this the use of indigo was prohibited in Saxony, in 1652, because it had operated so injuriously on the interest of woad-growers; and exclusive privileges were granted to those who engaged to use woad alone. The same restriction operated in France; and it was not until 1737 that dyers were left free to choose woad or indigo as their blue dye-stuff.

Wongshy is a yellow dye-stuff, obtained from the seed-vessels of a species of the Gentian family, and is, comparatively, a new dye. It is chiefly imported from Batavia.

Yellow Berries have been already described in connection with others produced from species of the Buckthorn family (which see).

The preceding are some of the most important sources of colour adopted in modern dyeing.

The following tables give some additional and interesting particulars:—

TABLE OF DYE AND TANNING MATERIALS, Etc., OBTAINED FROM PLANTS.

Common Name of the Article.	Botanical Name of the Genus and Species of the Plant used, or producing the Article.	Order or Family.	Native Place, or where Chiefly Grown.	Qualities, Uses, etc.
Alder Bark	Alnus glutinosa.	Betulaceæ.	Britain, etc.	The bark produces a yellow or red colour, and is used in dyeing; with sulphate of iron (copperas) it gives a black.—Also used in tanning.
Alkanet-root	Anchusa tinctoria.	Boraginaceæ.	Shores of the Mediterranean.	Used as a dye to stain wood; and as its red colour is easily imparted to oils, it is much employed to colour lip-salve, ointments, etc. "Port wine" is often coloured by it.
Aloes	Aloe (various).	Liliaceæ.	E. Indies, etc.	Some species of the aloe afford a brown dye; the leaves of the Socotrine Aloe give a rich violet colour that does not require a mordant to fix it.
Aniline	(See Coal-Tar Colours and Indigo.)			
Argol	Vitis vinifera.	Ampelideæ.	Europe, etc.	The coarse cream-of-tartar produced in casks in which wine has been stored, is extensively used in dyeing, for many purposes: it is known as Argol.
Arnotto	Bixa orellana.	Flacourtiaceæ.	S. America.	Arnotto is the red-coloured pulp covering the seeds of the plant. It is used as an orange or yellow dye for silks, and as a colouring matter in cheese, butter, and varnishes.
Barberry-root, etc.	Berberis vulgaris, etc.	Berberidaceæ.	Europe, etc.	The root, stems, etc., afford a yellow dye, and the bark can be employed in tanning leather.
Barwood...	(See Camwood.)			
Bedstraw	Galium verum.	Rubiaceæ.	Europe, etc.	The flower-tops afford a yellow dye with alum-mordant, and the roots a red dye, almost equal to madder.
Brazil Wood	Cæsalpinia brasiliensis.	Or. Leguminosæ. § Cæsalpinieæ.	West Indies, Brazil, etc.	The heart-wood of the tree is largely used to afford a red dye, and formerly to make red ink.
Broom	Cytisus scoparius, or sarothamnus: Scoparius, and Genista tinctoria.	Or. Leguminosæ. § Papilionaceæ.	Europe.	Used in dyeing yellow, and thus called "Dyer's Weed"; also for tanning, and in house-brooms.
Buckthorn	Rhamnus (numerous).	Rhamnaceæ.	Europe, etc.	Numerous species of Buckthorn afford dyeing materials. Sap-green is produced by the berries of the *R. catharticus*, and its bark gives a yellow dye. The bark berries, etc., of the Alder Buckthorn, *R. frangula*, are similarly used. Dyer's Buckthorn, *R. infectorius*, gives a bright yellow dye from the unripe berry. The French and Avignon, or Yellow Berries; the Persian Berries, used to dye Morocco leather of a yellow colour; and the Spanish and Turkey Berries, have a similar source.
Campeachy Wood...	(See Logwood.)			
Camwood	Baphia nitida.	Or. Leguminosæ. § Cæsalpinieæ.	W. Africa.	Called also Barwood. It affords the red dyes used for English Bandana handkerchiefs.
Catechu	Acacia catechu.	Or. Leguminosæ. § Mimoseæ.	E. Indies.	Also called Cutch and Terra Japonica, which is, however, from a different source. It is a kind of resin-like extract, much used in dyeing and tanning, on account of its containing much tannin.
Chica	Bignonia chica.	Bignoniaceæ.	S. America.	Affords a red pigment, and is used to give an orange-red to cotton goods. The Indians about the Oronoco used it for painting their bodies.

Coal-Tar Colours ...	—	—	—	As Aniline, Mauve, Magenta, Solferino, etc., which are all the product of coal-tar, and are separately noticed in this chapter. (See also Indigo.)
Cochineal	Opuntia cochinillifera.	Cactaceæ.	Mexico.	The Cochineal insect, *Coccus cacti*, feeds on this species of Cactus, and affords a most valuable scarlet and crimson dye. (See also Kermes, another species of *Coccus*, which feeds on the oak ; also Lac-dyes.)
Crottel	Parmelia omphalodes.	Lichenes.	Europe.	A lichen, growing on trees and rocks, which is occasionally used to produce a brown colour with copperas, sumac, and logwood.
Cudbear	Lecanora tartarea, etc.	Lichenes.	Sweden, etc.	A lichen, growing on rocks at high elevations, or in cool climates.—Used to give a purple or mauve colour, which is very fugitive, to woollen goods. It is similar to litmus and orchil, and is obtained, like them, by the action of ammonia on the lichen.
Cutch	(See Catechu.)			
Divi-divi...	Cæsalpinia coriaria.	Or. Leguminosæ. § Cæsalpinieæ.	S. America.	A very powerful astringent, and therefore much used in tanning. It is the fruit-pod of the tree.
French Berries ...	(See Buckthorn.)			
Fustet	(See Sumac.)			
Fustic	Maclura tinctoria, or Morus tinctoria.	Moraceæ.	W. Indies, Brazil, etc.	A wood which affords a well-known yellow dye. Sumac is sometimes called Fustic ; but it belongs to an entirely different order. (See Sumac.)
Galls	Quercus infectoria.	Corylaceæ.	Asia Minor.	There are several kinds of galls, or gall-nuts, all of which produce gallic acid. They are used in dyeing black, in ink-making, and, more rarely, in tanning. Their astringent properties make them valuable as a styptic in medicine. They are produced on certain species of oak, by the puncture of an insect, *Cynips Quercus-folii.*
Gambir, or Terra Japonica ...	Uncaria gambir.	Cinchonaceæ.	E. Indies, Malay Islands, etc.	An astringent substance obtained from the leaves, etc., of the plant by boiling, and much used in dyeing and tanning. In most respects it resembles Catechu—which see. It contains a principle called *Catechine.*
Garancine	Rubia tinctoria.	Rubiaceæ.	S. Europe, etc.	The dye-principle of madder, obtained from it by the action of sulphuric acid. (See Madder.)
Gum-trees	Eucalyptus (various).	Myrtaceæ.	Australia, etc.	Many of the *Eucalypti* of Australia contain an astringent principle which can be used in tanning.
Heaths ... ... Heather	Erica (various). Calluna vulgaris.	Ericaceæ.	Europe.	Some kinds of heath may be used in tanning ; and the Common Heather, *C. vulgaris*, affords a yellow dye with alum.
Henna	Lawsonia inermis.	Lythraceæ.	Africa, Arabia, etc.	The powdered leaves are used to dye leather, etc., of a reddish yellow, or orange ; and in Egypt it is employed by the women to give an orange colour to the nails, etc.
Indigo	Indigofera anil, tinctoria, etc.	Or. Leguminosæ. § Papilionaceæ.	India.	Indigo is a very valuable blue dye. Its manufacture, uses, etc., are described at length in this chapter.
Kelp	Fucus vesiculosus, etc.	Algæ.	Sea-shores.	Kelp is the ash of various kinds of seaweed, and affords soda, which is, however, now generally obtained from common salt.

Common Name of the Article.	Botanical Name of the Genus and Species of the Plant used, or producing the Article.	Order or Family.	Native Place, or where Chiefly Grown.	Qualities, Uses, etc.
Kermes	Quercus coccifera.	Corylaceæ.	S. Europe.	The Kermes, *Coccus ilicis*, feeds on the leaves of the species of oak, *Q. coccifera*, and affords a red dye like the Cochineal insect—which see. It is almost entirely replaced by the Cochineal species of *Coccus*, but its use is of very ancient date.
Kino	Pterocarpus marsupium. Pterocarpus erinaceus.	Or. Leguminosæ. § Papilionaceæ.	East Indies. Africa.	Two species which yield Kino, an astringent resin-like substance.—Used as a yellow dye for cotton in the East Indies. The *Eucalyptus resinifera* of Australia, called the Red Gum, and Iron Bark-tree, affords a resinous substance called Botany Bay Kino.
Lac-dyes	Ficus religiosa, etc.	Moraceæ, etc.	East Indies.	The *Coccus lacca*, by puncturing the tree named here (the Banian), and many others in the East Indies, produces Shell and other Lacs, that afford a beautiful red dye.
Lichen-dyes	Lecanora, Rocella, etc.	Lichenes.	Cool Climates.	Many genera and species of lichens give dyes, as Cudbear, Litmus, Orchil, etc.—which see.
Litmus	Rocella tinctoria, etc.	Lichenes.	Canaries. S. Europe, etc.	Extracted from the lichen by any ammoniacal liquor, and used to give a purple and lighter shade to silks.—Used in chemistry as a test for alkalies and acids. Also called Archil, or Orchil.
Logwood	Hæmatoxylon campechianum.	Or. Leguminosæ. § Cæsalpinieæ.	Central America, etc.	Much used in dyeing red and black colours, shades of purple, etc. It is also called Campeachy Wood
Madder	Rubia tinctoria.	Rubiaceæ.	France. S. Europe, etc.	A valuable root, employed to produce the celebrated Turkey-red, and other dyes. It affords *Garancine* by the action of sulphuric acid.
Madder (Indian) ...	(See Munjeet.)			
Mangrove Bark ...	Rhizophora mangle.	Rhizophoraceæ.	Tropics.	The bark of the Mangrove-tree is very astringent, and is accordingly used for tanning purposes.
Munjeet	Rubia cordifolia.	Rubiaceæ.	N. India.	A species of madder, used for the same purposes as the European kind, and also affording *Garancine*. (See Madder.)
Myrobalans	Terminalia (various).	Combretaceæ.	India.	The fruit of the tree: it possesses an astringent principle, and is much used by tanners.
Nicaragua Wood ...	(See Peach-wood.)			
Oak Bark	Quercus (various).	Corylaceæ.	Europe, etc.	The bark stripped from oaks is the chief material employed in tanning, on account of its containing much tannin. Also used in dyeing.
Orchil, or Archil ...	(See Litmus.)	Lichenes.	Europe.	Archil, or Orchil, is, properly, litmus in an early stage of preparation, when it possesses a purple colour.
Peach-wood, or Nicaragua Wood	Cæsalpinia brasiliensis.	Or. Leguminosæ. § Cæsalpinieæ.	S. America.	Used as a material for red dyes.
Pearlash, or Potash	Various plants.	———	Russia and America.	Procured by burning many plants, but especially wormwood, and lixiviating the mass,—Used for scouring wool, and for cleansing generally.

Persian Berries ...	(See Buckthorn.)	—	—	Afford a yellow dye.
Picric Acid	(See Coal-Tar Colours.)			
Pomegranate Bark...	Punica Granatum.	Myrtaceæ.	Europe, etc.	Used in dyeing, but especially to give Morocco leather a yellow colour.
Quercitron	Quercus tinctoria.	Corylaceæ.	N. America.	A valuable yellow dye, obtained from the bark of the tree.
Safflower...	Carthamus tinctorius.	Compositæ.	India, China, S. Europe, etc.	The flowers afford a yellow and red dye. The latter, which is the most valuable, is contained in but small quantities, and is much used in dyeing silks of various shades of rose-pink, and in making carmine-rouge.
Saffron	Crocus sativus.	Iridaceæ.	S. Europe, etc.	Used as a yellow colouring material, and obtained from the stigmas, or orange-coloured tops of the flower. Formerly much grown in England—hence the name of the town, Saffron-Walden, in Essex.
Sanderswood (Red) Santal-wood ... Saunders-wood ...	Pterocarpus santalinus.	Or. Leguminosæ. § Papilionaceæ.	India.	The wood affords a reddish-brown colour, as a dye, for woollen goods; also red and scarlet, with certain mordants.
Sap-green	(See Buckthorn.)			
Sappan-wood... ...	Cæsalpinia sappan.	Or. Leguminosæ. § Cæsalpinieæ.	India and Ceylon.	A wood much used as a red dye-stuff.
Spanish Berries ...	(See Buckthorn.)			
Sumac, or Sumach	Rhus cotinus. Rhus coriaria.	Anacardiaceæ.	S. Europe.	The powdered leaves and twigs are much used in tanning, and in dyeing orange-yellow and black. It is sometimes called Young Fustic, to distinguish it from Fustic—which see.
Tannin	—	—	—	A principle obtained from Galls, Oak-bark, and many other vegetable sources. It is owing to its presence in various astringent substances, that they are used in tanning. It has the power of solidifying the gelatine of animal substances, as skins, and thus converts them into leather.
Terra Japonica ...	Uncaria gambir.	Rubiaceæ.	Malay Islands.	Also called Gambir—which see. It is largely used in tanning and dyeing. Catechu is sometimes called, but erroneously, by its name. (See Catechu.)
Turkey Berries ...	(See Buckthorn.)			
Turmeric...	Curcuma longa.	Zingiberaceæ.	India, etc.	The powdered root (also called Indian Saffron) affords a yellow dye. Turmeric is used in chemistry as a test for free alkalies, which turn its infusion to a brown colour.
Valonia	Quercus ægilops.	Corylaceæ.	Greece. Asia Minor.	The acorn-cups of this species of the oak.—Much used as a tanning and dyeing material.
Weld	Reseda luteola.	Resedaceæ.	Britain, etc.	The leaf and stem yield a yellow colouring matter used in dyeing.
Woad	Isatis tinctoria.	Cruciferæ.	Britain.	Formerly much used to dye blue colours, but now superseded by Indigo. With it the ancient Britons stained the skin of their bodies.
Wongshy	Gentiana (?).	Gentianaceæ.	Batavia.	A yellow dye-stuff obtained from the seed-vessels of the plant.
Yellow Berries ...	(See Buckthorn.)			

It must be borne in mind that the same dye-stuff is capable of affording several different colours, according to the mode of treatment adopted with it. Logwood, for example, with an iron mordant, gives a bluish-black, if the iron be abundant; but with a less quantity of the mordant, a kind of slaty colour is produced. Many shades may also be obtained from it by using proper mordants. Indeed, there are few dye-stuffs that are converted, in the dye-house, to so many purposes as is logwood.

As a rule, alkalies, acids, and earths all greatly affect the results by their accidental presence; hence the remarks we made at p. 90, *ante*, on the necessity of pure water; that is, as free as possible from inorganic constituents.

Of course, the nature of the mordant used is one chief point of dependence in respect to the production of a permanent colour; and alumina—either as alum, the double sulphate of that earth and potass, or acetate of alumina, formed by the union of the earth with acetic acid, the pure acid of vinegar—is one of those most extensively employed. We have already, in general terms, described the use of mordants, and the derivation of the term; but we may here more extendedly examine their action, although their special uses, in respect to each colour required in dyeing, will more fully be considered in connection with the operation necessary for the production of such colours in yarns and goods.

It is obviously necessary that a mordant should, on being employed, be soluble; for, no matter how fine the particles of a solid body, they are far too coarse to be absorbed with the pores, or attached to the surface, of any textile fabric. Thus, if we were to attempt to mordant any such material by using the pure earth alumina, all such endeavours would fail. The nature of the solvent in which the mordant is dissolved, is a matter of the greatest importance in the chemistry of dyeing; for, if that solvent have too great an attraction for the base, then the fibres may not be able to detach it. Thus the affinity of sulphuric acid and alumina in common alum, is far too great to permit of that salt being used as a mordant for cotton goods, which have not sufficient attractive powers to separate the alumina, &c., combined. If, however, the acetate of alumina be used, as the acetic acid of this salt has comparatively a weak attraction for the alumina, the latter will attach itself to the cotton, and become a very powerful mordant. We have here a remarkable instance of the value of a knowledge of practical chemistry to the dyer.

The importance of mordants still further appears if we state that, with the exception of indigo, there is scarcely a vegetable colouring matter that will attach itself permanently to textile fabrics. There are certainly a few out of the list we have named—as, for example, the blue of indigo, and the red of safflower; but these, as exceptions, prove rather than disprove the universality of the rule. Logwood, for example, in a strong or weak bath, gives nothing but a stain to cotton; but, by a judicious selection of mordants, and a proper regulation as to quantity, violet, all shades from lavender to purple, blue to lilac, and from this to a blue-black, may be readily obtained.

It is also a matter of great importance that the quantity and mode of applying mordants should be regulated by a consideration of chemical principles. For example, if too great a proportion of mordant exist on the material before being passed through the bath of colour, a large proportion of the latter will be wasted, and precipitate as solid matter in the vat, instead of on the surface of the material. Hence, after such has been mordanted, it will be frequently necessary to remove all excess remaining on the surface of the fabric by thorough washing in water. But not only is the waste of the colouring matter caused by neglect in this respect, but even the character and regularity of the colour are affected, which would become dull and uneven. Besides these faults, a want of permanence would be probably resulting.

By a proper use of mordants, an effect called "*raising*" a colour is produced; and this is generally done by adding to the dye-liquor certain proportions of the same substances that have been used in mordanting the fabric already dyed in the vat. Apparently this leads to waste; and, indeed, it really does so; but a kind of bloom is produced on the material, that adds much to the brilliancy, perfection, or permanency of the colour; and, in producing these qualities, lies the great part of the dyer's art. The use of the same or another mordant than that which had been already added to the fabric is frequently indifferent; but, occasionally, both methods are adopted. Such substances are called alterants; although, for reasons evident enough, they do not in any way differ from mordants in their mechanical or chemical action.

It is remarkable that all mordants in ordinary use are oxides of metals. By this term we mean that the metal to produce them has been united with oxygen, the vital portion of air—a body forming $\frac{8}{9}$ths of the weight of water, and the most influential and active agent that chemistry acquaints us with. Alumina, for example, is an oxide of the metal aluminium, familiarly now known as used for the manufacture of many ornamental and useful metal objects. In Sir Humphry Davy's days this metal was quite a rarity; and but few years have elapsed since it has been produced in quantity. Now alumina is to aluminium as rust of iron is to iron in its metallic state. They are both oxides of metals. If such an oxide be dissolved in a suitable acid, they afford us what in chemistry we call salts; and thus alum is a salt of alumina; copperas one of iron; blue vitriol one of copper; in all of which the dissolving acid is sulphuric acid, or, as it is technically called, oil of vitriol.

In the preparation and use of all mineral substances, whether as mordants or sources of colour, chemical decomposition takes place. Thus the acetate of alumina loses its earth, which attaches itself to the fabric, and sets its acid, the acetic, free. When the acetate of iron is used to produce a black in a logwood or

sumach bath, the iron attaches itself to the fibre as an oxide, and this is seized upon by the astringent matter or tannin of the liquor of the bath, and a tannate of iron is formed. We therefore see that, in every branch of the art, chemical composition and decomposition take place.

With these preliminary remarks on the relation that subsists between vegetable colouring matter and that of a mineral nature, we may now turn to a brief description of the various alkaline, earthy, and metallic bodies that are or may be used in connection with the art of dyeing. We have already spoken in general terms of them at page 95, *ante;* but shall here give a list of the principal, not in alphabetical order, but arranged according to the system adopted by chemists, under which we recognise, in each group, certain allied properties. The present use of so many of these compounds in dyeing will be simultaneously explained. One of our chief objects of thus giving such a list, is to present those of our readers practically engaged in the art, but ignorant of chemistry, such information as may place them, to a limited extent, on a par with those who are at once practical dyers and practical chemists, or who employ a gentleman professionally in the latter position on their premises, provided with all the necessary appliances of a laboratory, &c. We feel sure that our work may fall into the hands of many not so favoured; and to these such an epitome cannot fail to be of value.

Chemical Agents, of use by the Dyer, or affecting his Operations.

Oxygen.—This agent, although never used in the gaseous state, is of the utmost importance in dyeing operations. Thus, a solution of copperas becomes oxidised by exposure to the air, which contains one-fifth of its bulk of this gas; and the stuff on which a solution of iron has been so deposited is coated with that oxide of iron, which alone takes a dye from logwood, sumach, and other baths containing tannin, or astringent matter. As we just previously stated, all the chief mordants are oxides of metals, or combinations of those bodies with oxygen. Under the old system of bleaching, the process depended entirely on the action of this gas, and moisture in the air. The brightening of many dyed substances is due to the action of this gas as found in the atmosphere, together with the application of steam. It is the chief constituent of some of the acids, and most of the chemicals used by the dyer. It is due to its action that the fine deep colour of Prussian blue is obtained. Most of the operations of dyeing depend on it, directly or indirectly.

Nitric Acid (also called *Aquafortis*) is an acid composed of oxygen and nitrogen, both constituents of the atmosphere. The chief use of this acid in the dye-house, is in the preparation of tin-liquor, to be hereafter noticed. A judicious addition of this acid to some metallic solutions, peroxidises them; but there is danger of acting on the fabrics immersed in such solutions. Silk may be converted into a rich yellow colour by the use of nitric acid; and picric acid is thus produced, and used in dyeing yellow. Nitric acid is prepared by distilling nitre with sulphuric acid, or oil of vitriol.

Chlorine.—This agent is of the utmost importance to the bleacher and calico-printer, the former using it, in the condition of chloride of lime, as his sole bleaching agent; and the latter frequently to discharge colours on some portion of any dyed surfaces, thus producing white or light patterns on dyed grounds. The chloride of lime was first used for such purposes at the close of the last century; and to Mr. Tennant, of Glasgow, its introduction was due. It has now entirely superseded the old mode of bleaching in the field by atmospheric action. The chloride, or bleaching powder, is one of the most important of modern chemical manufactures, and is extensively carried on, with that of soda and sulphuric acid, in Lancashire, Northumberland, Glasgow, &c. To the dyer, chlorine in any form is of little use. It discharges and destroys all vegetable colours.

Spirits of Salt, Muriatic (now called *Hydrochloric*) *Acid.*—This liquid is of much use in preparing tin liquor for the dyer, which is one of the most important agents, or mordants, employed in the dye-house. The acid is readily procured by distilling common salt and oil of vitriol (sulphuric acid) together. The gas given off is condensed by cold water. It is extensively afforded as a waste product of the manufacture of soda; and hence the dyer can always purchase it at a cheap rate.

Aqua Regia, or *Nitro-Muriatic Acid*, is a mixture of nitric and muriatic acids; and is used to dissolve tin, &c.

Sulphur is an abundant natural product in volcanic countries; but, in our own, is largely produced from metal ores containing it, as iron, lead, and copper pyrites. These have been much used, of late years, as a source of sulphur, in the manufacture of sulphuric acid, to be presently described. The wool-scourer and bleacher uses the fumes of burning sulphur, called, chemically, *sulphurous acid*, to whiten wool, which cannot be bleached by chlorine in any form. In the dye-house it may be rarely employed for such purposes, to give a whiteness to wool that is to be dyed of light colours; but, generally, this is unnecessary, as the wool, yarn, worsted, or woven goods, are, in most cases, so prepared before arriving in the dyer's hands. It may be remembered by him, however, that sulphur, in the form of sulphuretted hydrogen gas, frequently, and, indeed, constantly, arises from bad drains; and is often produced thus by the mixing of the waste liquors in the dye-house. When such occurs, any dye-colour derived from metallic sources, especially lead, is sure to be injured, as a black or brown tint, in such cases, is invariably produced by the union of the sulphur and the metal. For the same reason, if water be used that has much organic matter in it, all or most metallic solutions that are made with it will be injured. The water contained in vats that have not been used for some time, stinks of the gas

just named; and care should, therefore, be taken to have them perfectly cleansed before use. A small quantity of chloride of lime instantly destroys the gas thus generated, and "sweetens" the vessel.

Oil of Vitriol, or *Sulphuric Acid*, is one of the most extensive of chemical productions, and is used for bleaching, and frequently in dyeing and calico-printing. It is prepared by bringing together the fumes of burning sulphur, those of nitric acid, and steam in a leaden chamber, which, by a complicated process, result in the formation of the sulphuric acid. This is condensed by water at the bottom of the chamber. The liquid being drawn off and distilled, becomes the oil of vitriol. One of the most important uses of this liquid to the dyer is that of dissolving indigo; and for this purpose, that called Nordhausen is the most suitable. The bleacher uses it to make his souring liquids, which set free the chlorine after the goods have been removed from the bleach-tub, and also it dissolves out iron, that often would cause them to have a yellow tint. In combination, as in copperas (sulphate of iron), in blue vitriol (sulphate of copper), in alum, as sulphate of alumina and potass, &c., &c., this acid is of the highest importance in dyeing operations. In using it diluted with water, great care should be taken not to allow cotton or flaxen goods to dry with any sour on them, still less to freeze during winter; for, in either case, the fibre would be entirely destroyed—a result of by no means uncommon occurrence in bleaching establishments, especially with fine goods.

Pyroligneous Acid; Acetic Acid; Acid of Vinegar; Wood-acid; are all terms applied to the acid which gives the sourness to vinegar. The most impure is that produced by distilling wood in a close vessel, this form of the acid being used to produce the acetate of iron, so much used in dyeing black, as a mordant. The acetate of alumina contains acetic acid; as does also sugar of lead, or, as it is chemically termed, the acetate of that metal; hence, acetic acid, in any of its forms, is indirectly of great value to the dyer, dissolving, as it does, the metals we have named, and also others, to afford some of the most valuable of mordants. Verdigris is an acetate of copper.

Citric Acid, or *Acid of Lemons.*—This is often used to discharge colours by the calico-printer, because it has the power of dissolving away several mordants; but especially iron. Thus if a piece of black-dyed cotton cloth be wetted with this acid, the colour is immediately removed, and a white spot produced; the same is effected on some madder and other colours.

Tartaric Acid is similarly used with the preceding. It is obtained from—

Tartar, *Argol*, or *Cream of Tartar*, called, in chemistry, the *Bitartrate of Potass.* This article is of much value in many dyeing processes, of which mention will be made in their proper places. It is thrown down in an impure state during the fermentation of the juice of the grape, and is thus imported from wine countries as argol.

Oxalic Acid has similar properties with those of the citric and tartaric; but its use is much more limited. It is obtained in a variety of ways, as from sorrel, and many other plants; but, commercially, by the action of nitric acid on sugar.

Tannic and Gallic Acids—of great importance in dyeing black with salts of iron—have been already described as vegetable products, in connection with tannin, at p. 102, *ante;* and therefore need not here again be dealt with. The presence of tannic acid is a matter of common occurrence in the plants that afford dye-stuffs.

The preceding are some of the most important articles employed as acids, or otherwise, in entering into combination with other bodies in the process of dyeing, bleaching, and calico-printing. We next turn to what are called *alkaline* substances, of which three only are of use in the arts above named.

Pearlash, Potass.—This substance is obtained by burning certain plants, lixiviating or treating their ashes with water, and so obtaining a solution, which, on being evaporated, affords the pearlash of commerce. The value of this and the other alkalies consists chiefly in their power of uniting with fatty matters, and making them soluble in water; hence the production of soap, so largely used in all the arts with which we have here to deal. Soft soap is made of pearlash and fatty or oily matter. Leys are formed by dissolving pearlash or soda in water; and, to render them caustic, lime is added to remove the carbonic acid that generally, nay, universally, exists in the raw article. Such solutions readily remove oil and grease before dyeing or bleaching, that are almost constantly gathered on yarns or goods from the machinery, or fingers of the workers during the process of manufacture. Potash and the other alkalies turn vegetable yellows to a brown colour, and many vegetable blues into a green—circumstances occasionally taken advantage of in the dye-house, &c. Strong solutions of pearlash or soda have a tendency to harden yarn and goods.

Soda.—This is used in two forms—namely, as soda ash, and in crystals, the former being, in all cases, the most economical for all purposes of dyeing and bleaching. Formerly soda was entirely produced by burning seaweed to ashes, and then treating them in a similar manner to that just described as followed with wood ashes in the preparation of pearlash. But, at the present day, a very different plan is pursued. Common salt is acted on by oil of vitriol (sulphuric acid), by which sulphate of soda, or Glauber's salts, are produced. These are heated with chalk and small coal; and, by the subsequent action of water, the soda is dissolved out. Soda is more generally used than pearlash, because it is cheaper. The general properties are very similar, but soda produces hard or ordinary soap with oily and fatty matter. *Common salt* results from a union of sodium, the metal-basis of soda with chlorine, already described in connection with chloride of lime. *Nitre* is a substance containing potass and nitric acid. *Borax* is a compound of boracic acid and soda.

Ammonia, Hartshorn.—The two preceding alkalies are called fixed, because they are always met with in a solid state, when pure. Ammonia, on the contrary, is called a volatile alkali, because its natural state is as a gas. It possesses the power of turning vegetable colours to a brown colour, which, however, is lost as the ammonia passes off. Its chief use is in preparing orchil and other lichen dyes for the dyer's use, and also in scouring wools. For both purposes the ammonia, produced by putrefying urine, is employed as being the cheapest source of the alkali, all other modes of preparing it being too expensive for either of the purposes we have named. It answers better for scouring wools than either potass or soda, as it does not tend to injure their fibre; and, being volatile, it is easily removed. *Sal-ammoniac* is a compound of ammonia with spirits of salts (hydrochloric acid). When any animal matter is heated it gives off ammonia; and, formerly, as horns were thus treated to produce it, the name of *hartshorn* was given to this alkali.

We next turn to the consideration of such of the earths as may be useful, or the reverse, to the dyer. There are four, known as alkaline earths; called *Baryta, Strontia, Magnesia,* and *Lime.* The three first have no general relation to our subject; but the fourth has.

Lime.—This earth abounds in chalk, bones, &c.; and is an almost constant constituent of river and spring water. We have already, at some length, pointed out how prejudicial this may become to the dyer, at p. 90, *ante.* Caustic lime is of great use as a ley by itself, for it has alkaline and cleansing properties similar to potass and soda, already described; and, being exceedingly cheap, may be used unlimitedly, except it may injure any fabric exposed to its action. It is generally prepared by burning chalk, through which the carbonic acid is driven off, and the lime left in a tolerably pure state. In the dye-house it is of use to assist in the deoxidation of indigo, owing, in part, to its alkaline character (see *ante,* p. 99). Also, to render potash and soda caustic, as lately explained, for the use of the dyer, bleacher, and soap-maker. Its great affinity for animal matter makes it useful, in tanning, to remove hair from skins. One of its uses we decidedly demur against, for we have known it, as plaster of Paris, or sulphate of lime, replace cotton yarn after bleaching or dyeing, by which a fraudulent abstraction of the material has been effected, and that might escape all but the practical eye. Generally, on all vegetable colours its action is similar to that of potash and soda, previously described in connection with these alkalies.

Alumina.—This earth is the most important of all to the dyer, for it affords him one of the best of his mordants. It constitutes common clay when united with silica, or flint matter, and oxide of iron, which gives clay and bricks their yellow or reddish colour. As already noticed, it is an oxide of the metal aluminium, now so commonly employed in metal manufactures. Its combinations, in the form in which it is used by the dyer, are alum and the acetate of alumina.

Alum is largely manufactured in several parts of Great Britain, especially near Glasgow and Whitby, from a shale or slate. In this process, the raw material is either employed in its decomposed state (in which condition it also contains iron), or that decomposition is brought about by roasting it, and subsequently exposing the earth to air and moisture. It will be unnecessary for us here to enter into any description of the minutiæ of the process: we may state, however, that iron is a common and most harmful impurity for the dyer. It is easily detected by dissolving some of the suspected alum in distilled water, adding a few drops of nitric acid, and then a little solution of the yellow prussiate of potass; when, if iron be present, a blue precipitate of Prussian blue will be produced. A much purer alum is afforded by the alum-stone, found in some parts of Italy; and hence called Roman alum. This is quite free from iron. Occasionally it is prepared by dissolving pure alumina, just previously described, in dilute sulphuric acid, and adding potash or ammonia; for alum always is a double salt.

Acetate of Alumina, for reasons before given, is by far the best form of mordant, especially for cotton goods; alum, indeed, being all but useless for them. The acetate may be prepared in a variety of ways: one of the most simple being that of adding acetate of lead to a solution of alum, when the lead will fall down as sulphate, whilst the acetate of alumina is left in solution; a little soda being added to neutralise any free sulphuric acid. On the large scale it is prepared in a much rougher manner by using the impure pyroligneous acid, that contains the acetic. This liquid, formed by the distillation of wood, and partly purified, is neutralised with lime, by which the acetate of lime is afforded. This, again, is decomposed by adding alum; and thus the lime is precipitated as sulphate of lime, whilst the acetate of alumina remains in solution, in which condition it is sold to the dyers.

The great value of alumina in the art, as we have already explained, is its astonishing attraction for vegetable colouring matters, which it readily throws down from their infusions in water, or by being boiled in them. By thus acting simply on the liquids, the pigments called lakes, used in water-coloured paintings, &c., are produced. Noticing this fact, we are not surprised at its powers of fixing colours on cotton and other fabrics.

We next turn to metallic bodies, at least those so understood popularly; for it must be remembered that all the earths, with soda and potash, or pearlash, are really oxides, or rusts of metals, just as much as rust of iron is an oxide of iron. It will be better for us, however, to retain this popular division, because we are not now addressing the philosophical chemist, but the practical dyer.

Iron.—This metal is too well known to require any description. Exposed to the action of air and moisture, it soon becomes coated with a superficial covering, commonly called rust, but which the chemist terms oxide, because it arises from a combination of oxygen with the metal.

It is of great importance to the dyer to bear in mind the state of oxidation in which he uses iron solutions, because on that, as we have already pointed out when describing the effect of tannin on iron, depends the result of using iron as a mordant. A few explanatory remarks on the subject will, therefore, be of much value; and we shall endeavour to divest the subject of all technicality.

If a clean piece of iron be dissolved in a little sulphuric acid and water, a solution will be formed, that, on evaporation, will yield *green* crystals. This is what the dyer calls copperas; but the chemist terms it *proto*-sulphate of iron. Now: the word *proto* means first; and the chemist expresses by it the fact that the iron in the salt is in the *first state of oxidation.* If the crystals thus obtained be dissolved in a little water, and some tincture of galls is added, *no* colour will be produced, because of the iron being in a first state of oxidation. If, however, the same solution be heated with a few drops of nitric acid, or fuming aquafortis, the iron will pass into the second stage of oxidation; that is, it has gathered more oxygen. If a little tincture of galls be now added to the solution, a black colour will be produced.

Another experiment will show the same result, but in a different manner. Dissolve some of the green crystals in water, and add a solution of carbonate of ammonia; a *green*-coloured powder will fall down. Next pour off all the liquid, and so leave the green powder exposed to the action of the air. It will soon turn red, owing to the absorption of oxygen from the atmosphere; hence the philosophy and practice of using what we have called a *proto*-salt of iron as a mordant in the first instance, and allowing of its oxidation by exposure to the atmosphere, at a subsequent part of the process of dyeing. Numerous precautions are requisite in reference to this point; but they will come better under our notice when we enter into the details of dyeing individual colours.

Acetate or *pyrolignite* of iron is the mordant best adapted for most purposes when a black is required. The oxide and acid are held with less affinity than in copperas; and hence this salt is best adapted for dyeing cotton goods. Like the acetate of alumina, described at p. 111, *ante*, it may be prepared by aid of sugar of lead (acetate of lead); for, if a solution of copperas and one of this salt be added together, the lead will fall down as sulphate, whilst the acetic acid will unite to the iron. On the large scale, iron is gradually dissolved in pyroligneous acid (see *ante*, p. 110), when it forms a protosalt; and this is an excellent one for most purposes. There are methods of preparing it, which will be noticed hereafter.

For dyeing Prussian blue, a persalt of iron is needed; that is, one in which the metal has a high degree of oxidation, for the yellow prussiate of potass affords a greyish colour with a protosalt, that gradually, but irregularly, turns to a blue. The *nitrate of iron* is the best salt for this purpose, which is readily procured by dissolving clean iron in nitric acid. The yarn, or goods, are first immersed in a solution of this salt in water, which gives them a buff colour, owing to the deposition of the sesquioxide of the iron salt. On their being well rinsed, and afterwards put into a solution of the *yellow* prussiate of potass, a fine blue at once is produced. We may add that *red* prussiate of potass produces a blue colour with copperas, or any other *proto*-salt of iron; but, with a persalt, such as the nitrate, no blue is afforded, but only a reddish-coloured liquor in the bath.

Before we leave the subject of iron as a mordant, we may observe, that whilst, as a rule for all operations dependent on chemical action, soft water, free from the carbonate and sulphate of lime, should be used, it has been discovered that the presence of both of them is a somewhat favourable circumstance in dyeing black. It is remarkable that, in brewing, the same condition is desirable. If, therefore, in any place the absence of these is discovered to affect dyeing operations, the remedy is readily at hand; for sulphate of lime may easily be added, in the form of plaster of Paris, to the bath, and chalk will gradually supply, in *cold* water, the carbonate of lime. We should, however, fancy that, under the circumstances just referred to, other conditions might be considered. We have, nevertheless, stated the case as it has been put to us. It will be seen how desirable it is to have a competent knowledge of chemistry in dyeing operations.

Manganese.—This metal is, in many respects, chemically related to iron; although its salts, &c., afford no such colours with other bodies as iron produces. Manganese is chiefly used in calico-printing; and we shall partly defer its consideration to that subject. In the preparation of chloride of lime, and chlorine, it is essential; and hence is enormously used. Common salt, sulphuric acid, and the black oxide of manganese, are mixed with water in a kind of retort. On heat being applied, chlorine gas is given off; and in making chloride of lime, or bleaching powder, this is directed to trays of slaked lime. The earth gradually absorbs the gas, and is thus converted into bleaching powder. We may add, that the salts of manganese afford, by the action of ammonia and sulphuretted hydrogen, a flesh-coloured precipitate; and that potash and soda give a white precipitate, which turns to a brown-black by absorption of atmospheric oxygen; and it is in this condition that manganese is a dye or material for calico-printing.

Cobalt.—The expensive nature of the salts of this metal precludes its use for dyeing purposes; but one of its compounds, *smalts*, is much used for blueing cotton fabrics and paper. It is produced by roasting the cobalt, or *smaltine*, mixed with powdered flint and potass, the mass being afterwards ground to a fine powder.

Chromium, Chromate, and Bichromate of Potass; Chrome, Chromate of Lead.—All these substances, as products of the metal chromium, are of great importance in dyeing, &c., as most beautiful yellows to orange may be procured. The metal chromium is found united with iron, and derives its name from the beautiful colours

that may be obtained from its compounds, which are not only used in dyeing, but to colour glass, and to afford pigments. The compound of chromium of most importance to the dyer, is what chemists term *chromic acid*, which is formed, on the large scale, by heating the chromate of iron, or chief ore of the metal, to fusion with nitre. A chromate of potass is thus formed, which has a rich yellow colour. The bichromate, which is chiefly used in dyeing, is produced by removing one-half of the potass in the chromate by adding sulphuric or acetic acid, the latter being preferable for many reasons, because it produces the acetate instead of the sulphate of potash. The bichromate of the alkali is obtained in beautiful dark-orange crystals, sometimes of great size; some fine specimens of which we have seen produced by the manufacturers of this article in Scotland, where it is largely produced.

The great value of this substance is its power of producing yellow and orange colours on cotton goods, by forming an insoluble substance when united with lead; and also greens, by an indirect process. Most of the vegetable yellow dye-stuffs have, of late years, been replaced by it. By first passing the goods through a solution, composed of nitrate or acetate of lead, or the two salts combined, and subsequently through a solution of the bichromate, all shades, from a light lemon to a dark amber, are afforded. Orange colours are produced on the same fabrics by first dyeing them of a yellow colour, as just mentioned, and then immersing them in hot alkaline solutions, by which a portion of the chromic acid is removed, and an orange-coloured sub-chromate of lead is formed. Lime, as an alkaline earth, answers very well for this purpose. In a similar manner the pigments, chrome yellow, orange, &c., are prepared for the painter.

Green colours are produced, by aid of bichromate of potass, thus. The goods are first coloured blue by indigo, and subsequently passed through a solution of acetate of lead. The remainder of the process is similar to that already described for dyeing yellow by means of the chromium salts. In this method we notice an illustration of what we mentioned in reference to the production of green by combining yellow and blue light, at p. 86, where we described the general nature of colour in respect to light and the prismatic spectrum.

This method of dyeing by chromium salts is peculiarly applicable to cotton goods, which, as we before remarked, take the colours to perfection. We have produced dyed cotton-wool of every tint, from yellow to orange, by this method; and may here suggest that the full beauty of all these colours is only obtained by having the wool, yarns, or goods previously bleached, so as to remove the usual dusky tint of raw cotton. The chrome dyes have been also successfully applied to woollen goods.

Copper.—This metal is sufficiently well known to require no description. In the dye-house, and in calico-printing, its chief use is to produce a rich green, known as Scheele's, afforded by uniting copper with arsenic. The sulphate of copper is the chief salt employed: it is also known, in commerce and drysaltery, as Blue-stone and Blue-vitriol. It is produced, on the large scale, by converting the sulphide of the metal into sulphate by oxidation; by crystallising the liquid that is sometimes seen running out of copper mines, naturally produced by air and moisture, in the manner just described as its artificial mode of production; and still more rarely by dissolving clean copper in hot sulphuric acid. We may here warn the practical dyer, that we have seen many specimens of this salt in crystals, that have been mixed with sulphate of iron or copperas. These two salts readily crystallise together; but the adulteration, accidental or intentional, may usually be detected by noticing the colour of the compound. It is of a much lighter colour than the genuine article, which is of a deep transparent blue; and this also presents a regular large crystal form, that is soon distinguished from that of the adulterated article if the two be placed side by side. When arsenic, the white arsenic, or, as it is called in chemistry, arsenious acid, is boiled with the sulphate of copper and potass, a green precipitate is afforded, that is sold in the shops as "Scheele's green." It is a compound of arsenic and copper. The same pigment and colour are produced on fabrics by boiling them with the arsenic and copper, and passing them through a solution of potass or lime-water. The operation, however, is one of great danger to the workman; for if the hands be used in any part of the process, and wounds or abrasion of the skin exist, the worst consequences, and even fatal results, may occur, for both the copper salt and the arsenic are deadly poisons, even in very small quantities. Acetate of copper, or verdigris, similarly affords a green colour; but we believe that the use of either method is of but limited application. We may here mention, that a solution of sulphate of copper, mixed with one of the yellow prussiate of potass, affords a deep brown or mahogany-coloured precipitate, that can be fixed on cotton or other goods.

Zinc.—We are not aware of any employment of zinc, or its salts, in dyeing. They are all colourless, or rather white. *Cadmium* and *Bismuth* are also of no practical value to the dyer.

Lead.—The salts of this metal are of much value to the dyer, especially the acetate and nitrate, both of which are employed to produce the chromate, already described under the head of Chromium, as a source of yellow, orange, and green dyes. There are several oxides of the metal that have uses in the arts; as, for example, litharge, massicot, red lead, and minium, the two first being produced from the protoxide. Then, again, we have white lead, which is a carbonate, and a most valuable pigment.

Sugar of Lead is the acetate of the chemist; that is, lead united with acetic acid. There are several varieties of this salt, but we now confine our attention to that which is known as the sugar of lead. It is readily obtained by exposing metallic lead, in sheets, to the action of the acid, either in vapour or in the liquid form. The

carbonate is thus produced, with which another proportion of the acid unites. On the large scale, strong vinegar is used to dissolve either the lead in the metallic state, or litharge, its oxide just mentioned; and pyroligneous acid, described at p. 110, *ante*, in connection with acetic acid, is used for the sake of economy. If the ordinary sugar of lead be boiled with litharge, the basic acetates are formed, some of which have special advantages in dyeing with chromium salts.

Nitrate of Lead, used also for this process, is readily prepared by digesting red lead, or white lead with nitric acid. By the former process a brown powder is thrown down, which is the binoxide. It may also be prepared by heating the metal and nitric acid together.

There are two points in reference to the metal lead, and water, that are of vital importance to the dyer. We have mentioned, at p. 92, *ante*, a singular instance in which a friend of ours was greatly inconvenienced, and sustained considerable loss, owing to the waste of a lead mine being cast into a river from which, at some miles lower down, he took his water-supply for a paper-mill. But the dyer may find the same cause at home. If soft water be kept in a leaden cistern, it may gradually act on and dissolve the lead. At the junction of the air and water-line in the tank, the carbonic acid of the atmosphere produces a carbonate of the metal; and this becomes gradually dissolved in the water. Numerous cases of poisoning have occurred, in various parts of the kingdom, from this cause. But in the dye-house, it must be remembered, that all lead salts—that is, the oxide they contain—have great power in precipitating vegetable colours; and hence the presence of lead in water must, in the course of time, produce loss to the dyer. Not only so—in numerous cases a dulness or deadness of colour is caused, which would be prejudicial to his reputation.

Another point of importance is, that if hard water, containing sulphates or carbonates (see *ante*, p. 91), be used, and a lead salt, as the acetate, be dissolved in it, a milky appearance will be at once produced, owing to a precipitation of either the sulphate or carbonate of lead. This, of course, is all so much material wasted; and it is a matter of considerable consequence. We, however, see in this, as in many other dyeing operations, the necessity, in numerous instances, of pure or soft water. Rain-water, or the condensed steam from the waste-pipe of a steam-engine, may be used to dissolve lead salts when the ordinary supply is hard. The sulphate of copper (previously described) is similarly acted on by hard water—circumstances justifying the remarks we made generally on the purity of water, at p. 90, *et seq.*, where directions have been given that, in some cases, may afford a remedy for the hardness of the ordinary supply.

Tin.—This metal and its compounds are of the greatest importance to the dyer; for they afford him some most valuable mordants. They have been in use for dyeing purposes during nearly two centuries and a-half, having been first known about the year 1630, when it was discovered that cochineal affords a most brilliant scarlet by the action of a solution of tin on it. This is generally applicable to a great variety of dye-stuffs; as, for example, barwood, sappan-wood, logwood, Brazil-wood, &c.; and, generally, the results of the combination of tin with vegetable colours are of great beauty and permanency.

Various solutions are made of it, which are technically termed "spirits" in the dye-house; and, formerly, the preparation of them was considered a matter of peculiar secrecy and difficulty. Chemistry, however, has laid bare those secrets, and made common the exclusive possession of what, at one time, was an element in making the fortune of the dyer.

The chief solution of tin in use for dyeing, is what chemists called "chloride," but what is more technically known as "muriate," from the old exploded idea that muriatic acid is an oxygen acid. We consider that when a metal is dissolved in muriatic (now called hydrochloric) acid, a chloride of the metal is formed, analogous to an oxide, the nature of which we have previously described. Thus, what we now call chloride of potassium, was formerly *muriate of potass;* common salt, a chloride of sodium, was then the muriate of soda; and similarly, therefore, the chlorides of tin of the modern chemist were called muriates. Practically, at least to the dyer, there is no difference in the nature of these compounds, whether we call them muriates or chlorides; but when we regard them in the light of science, a very different course must be adopted, for we see certainly analogies in the new term, and new views, that enable us to reconcile many difficulties, and to form a larger range of analogies.

Tin is acted on by nitric, hydrochloric or muriatic, and the two acids combined; this mixture being called *aqua regia*, from its power of dissolving what were once known as the noble metals—gold, platina, &c. Practically, the solution in hydrochloric acid and nitric acid, mixed together in various proportions, is that which forms the "spirits" of tin for the dyer. It was formerly known as the "Fuming Liquor of Libavius"—a term that has now given way to those of the bichloride or perchloride of tin. This solution is readily formed by making a mixture of one part of nitric acid with three of the muriatic (hydrochloric), adding the tin by small quantities at a time, so as to moderate the action; for much depends (at least so practical dyers say) on the mode of preparing this solution. To a certain extent this is correct; for a too violent action decomposes the nitric acid, produces heat, and thus causes loss of the materials. There is a great tendency, indeed, in all solutions of tin to decompose, and produce either insoluble oxides or chlorides; and hence the necessity of considerable care in the production of each of its compounds. Many opinions have also been held in reference to the proportionate quantity of each acid; and although the scientific chemist of course knows, that however they may vary, still that a chloride of some kind will be formed with the metal, it by no means

follows that the practical results to the dyer will be the same. We have frequently had our own theoretical views checked, and sometimes reversed by practical men, utterly ignorant of science, but taught their business by long experience. This commonly occurs in science; thus the seafaring man and the shepherd, although they know nothing whatever of the laws of science, will yet be far more correct in their weather prediction than the most profound philosopher, be he meteorologist or astronomer.

We give the following quotation from the writings of one who seems practically acquainted with the question—that is, as a dyer—but with whose views on the chemical points we much differ; and in doing so, simply wish to show an impartial illustration of the opinion of those whom we do not hold with. The writer is anonymous; but sufficient evidence is given that he, in general, understands his subject. He observes—

"The first process of preparing spirits is to *feather* the tin. This is done by melting it in an iron ladle, and pouring it, when in a melted state, into a vessel filled with cold water, the hand to be held as high as possible, so that it may pour more in drops. The appearance of the tin in this state is, beyond description, beautiful. By this process of feathering, a very extended surface of metal is exposed to the acid, which facilitates its solution very much. If 'red spirits' be wanted—that is, a mordant for dyeing red upon cotton by Brazil-wood [see *ante*, p. 97] — the general method is, to take three measures of muriatic (hydrochloric) acid, and one of nitric acid [see *ante*, p. 109]; then add the tin by degrees to the mixture [which is equivalent to what is usually called *aqua regia*, described at p. 109, *ante*]. So long as the acids continue to dissolve it, care should be taken not to add the metal too rapidly, but bit by bit, adding one piece just as another is dissolved. We know that this is not generally attended to, as one handful of the metal is put in after another, at certain and too often irregular intervals of time, giving annoying results. When the metal is put in too rapidly, or too much at once, the action becomes violent, the solution gets heated, the nitric acid is decomposed, ammonia is formed in the solution, and a quantity of peroxidised tin falls to the bottom [which we consider to be a hydrate of the oxide], when the solution cools as a gelatinous precipitate, creating loss. When 'spirits' thus prepared are used for [producing] a brilliant red upon cotton by Brazil-wood, the proper hue is never obtained, the colour being always more or less brownish. The proportion of these acids for preparing the 'red spirits' is not invariably three to one, [for] the mixture [may] varies [vary] from [one] half to five to one, depending upon the taste and experience of the dyer [an opinion from which, as previously remarked, we must strongly dissent, because, whatever a dyer may fancy, chemical science does not, and cannot, vary]. Some also only dissolve a given quantity of the metal to the pound weight of the mixed acids, varying from one and a-half to three ounces to the pound; but according to our experience, the acids, in whatever proportions they are mixed, ought to be saturated—at least so far as they will become saturated—observing the precautions described [previously] above. We have also found, that when much nitric acid is used, the reds are generally deeper in colour, and have a very great tendency to turn brown, especially if the goods be dried in heat; but when the muriatic (hydrochloric) acid prevails, the colour obtained has more of the crimson or rose tint, and is not liable to brown in drying."

Much of practical information is given in the preceding quotation; and perhaps it may be much more intelligible to those who are simply guided by practice than by theory, beyond any really scientific statement of the facts of the case. We by no means blame those who follow such practical advice, provided they are sure that all the circumstances of strength, specific gravity, purity, &c., have been as completely provided for as the writer whom we have quoted must be supposed to have made himself acquainted with. But on such points depend the value of his advice; and hence the difference between him and ourselves. We *know* that there cannot be anything in the shape of accident in applying chemical principles, and therefore can make no allowance for such conditions.

We shall, however, enter, at a future page, into more practical details on this subject.

Antimony.—We are not aware that this metal is, to any extent, or in any form, employed in dyeing operations. It will be, therefore, sufficient for us here to state, that it gives a red precipitate with sulphuretted hydrogen, or the same dissolved in ammonia (the hydrosulphate of ammonia, or sulphide of ammonia, with sulphur); a white hydrate with caustic alkaline solution; its sulphide, the native tersulphide, so much used in fireworks, is soluble in hydrochloric or muriatic acid; and beyond this, no question of importance to the dyer can arise, so far as we know, in reference to dyeing operations.

Arsenic is much allied to antimony in many of its chemical characteristics. We regret to say that it has been largely used, of late years, in producing "greens," that have caused serious, if not fatal accidents. Under the head of *Copper*, we have already alluded to Scheele's green, as a combination of that metal and arsenic, produced from sulphate of copper, an alkali, and arsenious acid, or white arsenic; and strongly condemned the use of such substances. It is a very erroneous, but equally widely-diffused, opinion, that metallic substances, and their oxides, salts, &c., are of so solid a nature as not to be liable to pass off, or evaporate, under ordinary circumstances and temperatures. Such is a great mistake. Now, no one, for example, would imagine that mercury, whose boiling-point is no less than about 650°, could be evaporated at a temperature not much greater (140°) than that at which the human hand would be scarcely hurt if immersed in water at that degree of heat. And yet the success of the Daguerreotype process, in photography, *actually depends* on this fact. Similarly, other metals

are equally volatilisable, although the majority of mankind is not blessed with sufficient chemical or nasal sense to discover the fact, until the effects on the system have so far advanced as to be serious, if not dangerous.

In respect to arsenic, we have a metal easily volatilisable at comparatively low temperatures, and in the form of white arsenic (arsenious acid); Scheele's green (arsenite of copper), &c., really dangerous, because, in extremely fine powder, it is readily blown about by the slightest wind, or disturbance of any kind. Hence the danger of ladies' dresses dyed with a salt of arsenious acid, or any compound of arsenic; artificial flowers, on which the rich green bloom of the leaves arises from some arsenite; and paper-hangings, &c., &c. Partially, such objections arise against the use of *pigments*; as, for example, in paper-hangings; but still, it is notorious, that within the last few years, ladies' dresses have been sent out from the dye and print-house, covered with a material that ought to be an evidence of premeditated manslaughter—not to say murder—against those who have been the producers of such colours, or such materials.

It is useless to urge that the buyer should be aware—"*Caveat Emptor.*" We do not expect women to carry tests for arsenic into a draper's shop. We should, therefore, not be doing our duty as one professionally following science, did we not enter our protest against the use of arsenic in such forms as we have indicated. Other cases arise in which the use of arsenious acid is perfectly harmless, and is then not to be objected to. What we earnestly oppose, is the use of such materials in dyeing, or calico-printing, or other processes that result in sending out any fabric whatever in such a condition that the arsenic (combined or otherwise) can become of the slightest danger either to worker or wearer.

After the expression of opinion on the subject that we have made, it will be by no means beyond the sphere of our duty, and still less of our inclination, to point out how a "conscientious" manufacturer may detect *laches*, in this respect, of others in the trade; and in so doing, we feel assured that we shall have the approval of every honest and well-wishing member of society.

As already stated, one distinguishing characteristic of arsenic, in almost every form, is the ease with which it is converted into vapour. Now, although the pure metal has no smell when heated, white arsenic—that is, what the chemist calls *arsenious acid*—has; hence, as a rule, we have an easy mode of testing its presence. Thus, if a little white arsenic be heated on a piece of charcoal, and, indeed, on any solid matter that is not of itself readily volatilisable—as, for instance, a piece of glass tube, the blade of a knife, &c.—a smell resembling garlic will be perceived, that is due to the volatilised arsenic. If, for instance, a piece of paper-hanging, or a portion of a cotton dress, supposed to have been dyed with some compound containing arsenic, be heated in a glass tube to a little below a red heat, a smell of an onion-like odour will be perceived if arsenic be present. At the same time, some portion of the tube will be covered with a white crystalline powder, which consists of the volatilised white arsenic; whilst another, and inner ring, will present a grayish metallic appearance, due to the deposition of the real metal arsenic.

Another method is to digest the suspected article with a little acetic or muriatic acid in a flask. Some sulphate of copper and ammonia added to this solution, will give a green arsenite of copper; a few drops of nitrate of silver and ammonia, added to a solution in acetic acid, will afford a yellow arsenite of silver. There are other methods, but of too refined a use, except for those accustomed to chemical analysis.

The most usual forms, otherwise than that of Scheele's green, in which arsenic has been used in dyeing, is that of producing a sulphide of arsenic of a yellow colour, and known native as *Orpiment*; but we believe that this method of employing it is now entirely disused.

Mercury.—We are not aware of any use that is made of salts of mercury in the dye-house as a dye material. The only colour that could be of value would be that resulting from the union of iodine with mercury, in the form of an iodide. This has either a rich yellow or red appearance; but is too uncertain and expensive for dyeing purposes, for which reason it is equally unsuitable as a pigment, although the red iodide has one of the most beautiful colours imaginable. Vermilion and cinnabar are two highly prized pigments; but their artificial production on textile fabrics has not been brought to any practical result.

The remainder of the metals are all too expensive for any application in the dye-house. They embrace silver, gold, platina, and many others, whose uses are confined to objects in the manufacture of which a large comparative expenditure is of no importance; or wherein a small portion of the metal, its oxide, or salts, "go a long way." For example, gold is used in ornamenting china ware, both as "gilt" and on account of its producing a rich purple with tin; platina is "burnt in" on the exterior of some kinds of pottery, to afford a surface having a metallic appearance; uranium is used for tingeing glass of a rich yellow-green; and so on. Of late years it has been recommended to dip muslins in a solution of tungstate of soda, a combination of the metal tungsten and soda—a proposition that has been little heeded, although its object was to render uninflammable that material as usually employed in female dress, curtains, &c., and promising the best of preventive results. We have, however, not yet arrived at that period of civilisation when science, or rather common sense, can exert any sway over the folly of fashion; and, therefore, the cynical philosopher may yet have occasion to rejoice that a large field is still left for the exercise of his talent.

We therefore dismiss the subject of metallic bodies, as amongst the chemical substances that may be used in dyeing, and proceed to others of occasional or special use, not yet mentioned, but still of what we may generically call a chemical character, according to the technical phraseology of the dye or bleach-house.

Prussiate of Potash, Yellow Prussiate, Ferro-cyanide of Potassium.—The two first are the commercial, and the last the chemical term of the salt on which the dyer depends for producing Prussian blue, in combination with a *per*-salt of iron (see *ante*, p. 112). The yellow prussiate is a compound of cyanogen, the alkali potash, and iron. Cyanogen, again, is a compound of carbon, or pure charcoal, and nitrogen—a gas forming four-fifths of the bulk of the atmosphere; a constituent of nitric acid, or aquafortis, and, therefore, of nitre. Nitrogen, also, is an important element in all animal matter; hence the reason of our obtaining ammonia by heating horns, &c., as already explained at p. 111, *ante*. As we shall presently find, cyanogen is similarly procured for the purpose of forming the salt that we are now describing.

The yellow prussiate of potash is called, in chemical language, *ferro*-cyanide of potassium, because of its containing the latter metal, which is the basis of pearlash, or potash, and iron (Latin, *ferrum*); for it is the distinctive character of chemical nomenclature to declare, as far as possible, the constituents of the substance to which a name is applied. This is a great advantage, and would be so in the dye-house. For example, the term "spirits" is applied to tin-liquor and hydrochloric acid; but these have no relation or likeness whatever to spirits of an alcoholic nature. The term *prussiate* is derived from the fact that one of the elements of prussic, or hydrocyanic, acid is present in the salt; and, in the younger days of chemistry, it was imagined that the prussiate was really constituted of prussic acid and potass.

The usual mode of preparing this salt affords an admirable instance of the manner in which chemistry teaches us how to utilise waste substances. All sorts of waste animal matter are used for this purpose; as, for example, hoofs, pieces of old leather, parings of hides, blood, woollen rags, horn, &c., &c. These are either first dried and calcined with potash, or are thrown into an iron vessel built into a furnace, where they are heated to fusion, and the vapours and gases produced are allowed to escape. On these ceasing to be afforded, the vessel is closed, and the heat is raised. The iron pot is acted on, or pieces of iron filings are thrown in. Thus a combination takes place between the potassium of the potash, the iron, and the cyanogen produced by the burning animal matter, resulting in the formation of a fluid mass, that constitutes the impure prussiate. After this has been repeatedly stirred, it is taken out and cooled. When quite cold, the solid matter is dissolved in water, and filtered. Precautions are taken to remove a salt called cyanide of potassium, that is simultaneously produced; the liquid is then evaporated, and crystallisation ensues, when the salt is afforded in beautiful lemon-coloured crystals.

The chief, and, we may almost say, the sole, use of this salt in the dye-house, is to produce on cotton goods the pigment called Prussian blue. For this purpose, as already named at p. 112, *ante*, a persalt of iron is required; that is, one in which the iron is in a state of higher oxidation than as found in the sulphate of iron or copperas. The goods are first dipped into a solution of the nitrate of iron, which is a persalt; they are then washed in water, and subsequently put into the prussiate tub—a vessel in which the prussiate of potash has been dissolved with the addition of a little sulphuric acid; the object of the latter being to unite with the potash set free during the operation. By this means, proportionate to the strength of the various solutions, Prussian blue dyeing is effected.

We have previously noticed that the *yellow* prussiate of potash requires a *per*-salt of iron; for with the *proto*-salt, as copperas, only a gray-white tint is produced, turning blue, at last, by exposure to the atmosphere. Another salt, however, known technically as the *red prussiate of potash*, but in science as the ferri-cyanide of potassium, may be employed, which gives a blue immediately with copperas. This salt is produced by passing a current of chlorine gas through a solution of the yellow prussiate. The liquid becomes converted to a red colour, and affords, on evaporation, red crystals. At present this salt has not been used, owing to its high price compared with the yellow prussiate.

The sulphate of iron, or copperas, may be peroxidised by simple means. It is that of adding a little nitric acid to a solution of it, and boiling until no more red fumes are given off. The solution thus obtained may be used in place of the nitrate, than which it is much less expensive. Another method that we have experimentally, but not practically adopted, is that of adding a few crystals of chlorate of potash and a little sulphuric acid to a solution of copperas. The chlorate of potash is decomposed, and affords oxygen, by which the iron of the copperas is peroxidised as effectually as by nitric acid. A solution of this kind affords Prussian blue with the yellow prussiate.

At p. 113, we have mentioned that the yellow prussiate of potash affords a brown or mahogany colour with the sulphate of copper. It is occasionally used in the dye-house for communicating these colours.

About twenty years ago, cotton yarns and twist, for trimming, sewing, and other purposes, were dyed by the Prussian-blue process to a great extent. There is, however, one great objection to its use; and that is, the colour is anything but permanent. Soap, and any alkaline solution, at once acts on all the colours that can be thus produced—from the lightest blue to the darkest mazarine. The colours first turn green, and then are gradually destroyed; although, by the addition of an acid solution, which neutralises the alkaline one, the loss may, in part, be restored. The action of sunlight is equally unfavourable to the permanency of all colours, whether blue or brown, produced by combinations of the prussiate of potash. The use of this salt in calico-printing will be noticed hereafter.

We may here bring before the notice of the practical dyer a colour that arises from the use of a cyanogen compound, with which we are only

personally acquainted in the laboratory, and have never attempted to apply it to dyeing purposes; nor are we certain that it has not been so applied. We merely mention it, therefore, for the consideration of the practical man.

If the yellow prussiate of potass, or ferrocyanide of potassium, be heated with sulphur and a little carbonate of potass, a new compound of cyanogen, called *sulpho-cyanogen*, is produced. The fused mass thus afforded is dissolved in water, when a sulpho-cyanide of potassium is produced. To obtain this pure, the solution is evaporated to dryness, and washed with hot and strong spirits of wine (alcohol); and from this crystals will be deposited on cooling. If these be dissolved in water, and added to a solution of a persalt of iron, they afford a liquid of a rich blood colour. Whether this could be permanently fixed on cloth we do not know; but perhaps some of our practical readers may be induced to try the experiment.

We may briefly add the general results of using the two prussiates of potash combined with metallic oxides, including such as we have mentioned; for although, perhaps, of no great practical use, they may serve either as a guide to further experiments, or prevent time being wasted. These are as follow:—

Metals.	Yellow Prussiate.	Red Prussiate.
Protoxide of iron	Gray, turning to blue.	Blue.
Peroxide of iron........	Blue.	Red liquor.
Protoxide of manganese	White, turning to red.	Brown.
Peroxide of manganese..	Green.	
Protoxide of copper	Brown, or mahogany.	Yellow-green.
,, ,, zinc	White.	Yellow.
,, ,, tin	White.	White.
Peroxide of tin	Yellow.	
Peroxide of lead	Yellow-white.	

From which it will be seen what colours may be derived from the various combinations of the prussiates with metals.

We have thus described some of the most important chemical substances employed by the dyer, so far as they are of inorganic origin, partially or entirely. We may now briefly direct attention to others that relate more to organic matters, or rather, are the productions of animated existence. They embrace both vegetable and animal products, but are different from those already described.

Starch, Gum, &c.—The dyer has nothing to do with these; but the calico-printer much depends on them for "placing" certain substances on the surface of the cloth, to resist or receive the effect of dye-liquids. The finishing of bleached calico is often effected by the addition of starch-matter, which gives an even texture to the surface of the cloth, although we cannot, at all times, suppose that this is done in a manner exactly consistent with commercial honour. The technical term applied to this mode of treating bleached calicoes, is that of "dressing." In certain cases we have detected the presence of sulphate of lime in cloth so treated; but whether intentionally added by the bleachers, or present as an adulteration of the flour used, we cannot decide.

In former years, wheat flour was largely used for dressing calico by the calenderer; but, at the present day, starch obtained from the potato has come into use. This result arose, we believe, at first from an attempt to use potatoes that were affected with the "disease" that broke out some years ago, and produced what was then termed the "potato famine." This potato starch is readily convertible into dextrine by heating it to a temperature of about 400°, when it partakes, amongst other qualities, of that of gum, so far as its adhesive power is concerned; and in this form is now employed as the adhesive material for the back of postage-stamps. No doubt but that it may be, in most cases, similarly employed by the calico-printer, in place of the ordinary gums soluble in water.

Some years ago, a very ingenious application was made to dyed twisted cotton, by which it was converted into a material that could be employed with silk, as a "backing" for silk velvets; and most extensively was it used for this purpose, as we can personally vouch.

Cotton yarns, as our practical readers know, consist simply of a single thread, or filament, twisted from the wool in the ordinary course of spinning. Two or more of these, twisted together, give rise to what are called "doubled yarns." The kind to which we allude were simply two of these filaments or single yarns, of great fineness, and running from what is called in the trade, 100s. to 200s., or even higher; that is, 200 of such single hanks, measuring each about half a mile, are required to weigh one pound avoirdupois. These, on being dyed black, were passed through a strong solution of gum-senegal or tragacanth; and they thereby attained sufficient stiffness to withstand the fraying of the loom when woven with silk. Before dyeing, they were "gas-ed;" that is, they were passed through the flame of gas sufficiently often to burn off all the fibre that stands out as a rough edge to ordinary cotton twist—a method also adopted in preparing calicoes for the bleacher.

Bran.—The exterior, or husk, of corn was formerly much extolled for a variety of purposes, and was accredited with the power of loosening and removing vegetable colouring matter, and of even altering the tints themselves. We are pretty well acquainted with all the effects that fresh or decomposed vegetable and animal matter can produce; and now much more speedy and effectual means can be had recourse to than some of the old empirical methods, that had neither reason nor rhyme for their employment.

One point of considerable importance may be here mentioned. It is, that all substances ranking under the head of starch, gums, &c., are readily decomposable; and frequently, with heat and moisture, produce acetic and other acids. This may often be noticed in highly "dressed" cloth, in which, if air and moisture be abundantly present, decomposition will take place;

hence a frequent cause of mildew in bleached goods, that never, or rarely, attacks cotton in the wool or yarn condition, antecedent to bleaching. In our time we have purchased large quantities of cotton wool and waste; and, except under special circumstances, rarely noticed the destruction of the fibre from such causes. Accidentally this result is frequently prevented by the remains of chlorine that occur in highly or carelessly bleached goods. The presence of this gas is highly prejudicial to the formation of fungus growth in cotton—a hint that may, perhaps, be of value to some of our readers.

It must be remembered that the chemical constitution of cotton, all kinds of flax and hemp, starch, dextrine, and gum, does not greatly vary; and the agents that act on one, act almost equally on all. Thus cotton, linen, starch, and dextrine, may all be converted into grape sugar; a cotton shirt is capable, by certain chemical treatment, of affording as much grape sugar as it weighs; and few persons beyond the sphere of scientific circles, would believe that this article of dress may not only produce grape sugar, but also spirits of wine, or alcohol, acetic acid, guncotton, &c., &c. So wonderful are the changes that a study of pure science affords. Practically, and to the dyer, these facts are of value, because they explain to him why and how it is, that, under certain circumstances, he may accidentally injure the fibrous materials placed in his charge. In addition to air, moisture, and heat, already named, we may add the action of sulphuric and nitric acids, as productive of such results under circumstances of careless treatment.

One of the great preservatives of raw cotton or flax—that is, those materials in their unbleached state—is the presence of a resinous matter. As pointed out at a previous page, the solution of this matter may be effected by the action of alkaline leys, in which the resin is soluble. After boiling cotton, &c., in such solutions, the latter attain a dark-brown tint and an aromatic odour; and, by the addition of an acid, the resinous matter is readily precipitated in a solid condition.

Spirits of Wine, Alcohol.—The latter is the generic title, in chemical science, of the result of vinous fermentation, as producing the intoxicating portion of wine, beer, spirituous liquors, &c. When grape juice is left to itself for some time, at a moderately high temperature, containing, as it does, a peculiar principle, it undergoes spontaneous fermentation, that produces alcohol, or pure spirit, chiefly in proportion to the grape sugar resident in the juice. Malt, in which the starch has been converted into sugar by partial germination, also affords alcohol, or spirit, when yeast is added to its infusion in water; and if either of the liquors so prepared be distilled, spirit will be produced, that can be separated from its adherent water by subsequent distillation with potash or lime, which, having an affinity for the water, retains it, the spirit passing off in a state of tolerable purity and strength.

The spirits of wine of commerce is a liquid of very varying strength. It should contain about fifteen parts of water combined with eighty-five of absolutely pure spirit; and have a specific gravity of ·840; water equalling 1·000. In other words, if a bottle filled with distilled water, at a temperature of 62° Fah., held 1,000 grains of that liquid, and it was, after being carefully dried from all adherent water, filled with spirits of wine, the same bulk of the latter should only weigh 840 grains. But this strength is rarely attained in commerce; and hence the spirits of wine generally purchased has a greater specific gravity than that we have indicated; or, in other words, approaches nearer, bulk for bulk, to the same weight as water.

In the dye-house the use of spirits of wine is rare; and, at the present day, is so exceptional as not often to occur. In respect to the aniline dyes, we shall have here to notice some peculiarities of the action generally, and the solvent powers, of alcohol on them.

But to him who engages in dyeing as a business, guided by scientific principles, alcohol, or spirits of wine, frequently becomes of much value. Most vegetable colours give a tincture—that is, a solution—in spirits of wine; and hence a ready and convenient method exists of extracting and retaining what we may term specimen colours. And, usually speaking, such tinctures are equally susceptible of experiments as those solutions effected by infusion or decoction of the dye materials in water, whilst they have the great advantage of "keeping;" that is, they are not liable to spontaneous decomposition, growth of fungus, and the like effects.

Ether.—This is a product of the distillation of alcohol with sulphuric acid. It has no practical use in the dye-house, for it is exceedingly expensive at first cost; but if, at that point, it was as cheap as water itself, its volatility would render it highly costly. Like alcohol, or spirits of wine, it is fitted as a menstruum, or solvent, during research. For example, as already pointed out at p. 102,' *ante*, it may be employed to separate the tannic and gallic acids, found in galls, and other materials containing those substances.

Wood-spirit, &c.—The products of the distillation of wood are only of interest to the dyer so far as they afford pyroligneous acid, used to produce the acetates of iron, alumina, lead, &c.; and these have already been explained in an earlier part of this article, both in respect to their preparation and uses. Connected with other arts, wood-spirit is of interest as being a constituent of methylated spirits, which, by the way, may frequently and cheaply be substituted for spirits of wine, that we have just been describing.

Benzole, as a vegetable and coal-tar product, will be mentioned hereafter in connection with the aniline colours. Formerly, that branch of dyeing carried on with "cleaning," as of silk, gloves, &c., was partly dependent on turpentine. Now, however, benzole, or, as it is more usually called, benzine, has entirely substituted that article, and possesses numerous and superior advantages in several respects. Benzole is also a product of benzoic acid (itself a product

of gum benzoin), from which it may be obtained by distillation with lime; but this method is far too expensive to permit of its commercial manufacture. Benzole, obtained either from this source or from the waste liquor in gas-making, is equally productive of aniline, as we shall hereafter notice.

Oils, Soap, &c.—We have already frequently pointed out that great difference exists between the dye-taking powers of cotton and those of animal matter, such as wool and silk. In the original method of dyeing Turkey-red, this difficulty is in part avoided by the use of Gallipoli oil during a part of that long process. Generally, however, it is desirable to get rid of all oily and fatty matters; and this is effected by passing the yarns or goods through alkaline leys containing pearlash, soda, or lime.

Soap of all kinds is strictly a chemical compound, formed by the union of an alkali (generally soda) with the stearic and other acids contained in fatty matters. The latter are derived from various sources; many vegetable oils, such as palm, cocoa-nut, &c., &c., being employed for that purpose. Amongst fats, are those of all the domestic animals, as the ox, sheep, horse, &c., the fat of the latter being largely derived during the operations of the bone-boiler, who first extracts all grease, which, saponified, answers well for making low kinds of soap.

The chemistry of soap-making is highly simple, and yet exceedingly interesting. It is well known that fat, or oil, will not, under ordinary circumstances, mix with water. If, however, in the case of oil, a cold solution of a caustic alkali—as, for example, soda—be shaken up with the oil and water, a union will at once take place, and a kind of milky solution is formed.

In the case of animal and other fatty matters, heat is required to reduce them to a fluid state. Caustic soda, if then boiled with them, produces precisely the same effect as with the oil above stated; with this exception, however, that the solution, on cooling, becomes solid. Soft soap is made by using pearlash or potash as the alkali; whilst hard soap results from the use of soda (see *ante*, p. 110). Before either alkali is employed, it must be rendered caustic by the addition of lime, which seizes its combined carbonic acid, and sets the alkali free.

The manufacture of soap is now so extensively carried on, and competition has so much reduced the price, that, except on a very large scale of use, it is far better and cheaper for the dyer, and other consumers of the article, to buy, rather than make it. We generally find, that in all articles of large consumption, their production is best carried on by individuals, or firms, who devote their sole attention to the manufacture of one article, rather than dividing it amongst several. For example, if a firm manufacture soda largely, it follows that they can more cheaply produce soap than they who have to purchase the alkali, for both go into the oil market, at least, on equal terms. The manufacture of soda leads not only to that of soap, but to that also of sulphuric acid, which, under the present system of soda-making, is an essential material. It would thus appear that a firm so engaged has three manufactures in hand; but they merge into one, commercially and pecuniarily, for each branch is essential to the other. Thus, in the case we have supposed, soap is really the ultimate result of their production, as it is that manufacture which essentially calls for the other two, or at least absolutely requires them. It has hence arisen that most large producers of soap have also introduced into their establishments the manufacture of soda and of sulphuric acid, the example having been set them by the makers of the latter article, who, during the last few years, have engaged in the soap manufacture.

Amongst the cheapest soaps are those made of fish-oil, resin, kitchen fat, &c.; some of which are quite good enough for all purposes of the dyer or scourer. They have a tendency, however, to give an unpleasant smell to goods, that is scarcely removable by the most complete washing. It must also be borne in mind, that, generally speaking, all low soaps contain a considerable quantity of free alkali, which, unless entirely removed before dyeing operations, might have a very prejudicial effect on certain colours. Prussian blues, and all other colours dyed with prussiate of potass and a metallic oxide, are completely destroyed by soaps, because of the alkali present. Of course, all soap must contain a certain proportion of free alkali; but it is to the great quantity in certain descriptions, and not to its actual presence, that we here draw attention.

It would almost appear as an insult to most of our practical readers, if we told them that acids decompose soaps, seize on their alkali, and set the stearine, &c., free. Yet there is some reason for us to name this fact, as we have had evidence by an occurrence which not long ago came under our notice. A large manufacturer bought a great quantity of waste, in which both cotton and wool were present. To give a white colour to the cotton, he acted on it by chloride of lime and sulphuric acid. The material was badly washed in water, and subsequently run through soap and water, to cleanse the wool. The result was that a sticky and fatty mass was thrown down, that caused him great annoyance. But in all cases, great care should be taken that every particle of soap be removed before any goods are immersed in an acid solution; and *vice versâ;* for neglect of this would cause the stearic acid, or stearine of the soap, to be set free, and most probably result in a vast amount of inconvenience, if not the entire spoiling of the goods.

Animal Matters.—The essential difference between flax and cotton, and wool and silk, consists, chemically, in the fact that the two former are destitute of nitrogen, which the latter possess—nitrogen being an almost invariable constituent of animal organisms, products, &c. Whether or no the readiness with which wool and silk take dyes, and the perfect manner in which they retain them permanently, is due to this chemical difference in the consti-

tution of the two classes of fibres, we cannot accurately determine; but it is a fact that the addition of animal matter to cotton in Turkey-red dyeing is essential to its success and permanency. Blood has been used for this purpose. Its chemical composition, so far as it can affect dyeing operations, is accurately known; the principal constituents in that respect being albumen, fibrin, and casein—all so near alike in chemical characters as to be little short of being alike when submitted to ultimate chemical analysis, so far as their carbon, nitrogen, hydrogen, and oxygen (the four chief constituents) are concerned. Whether or no the blood imparts to the cotton certain chemical characters, that thus invest it with the new power of permanently retaining colour, as before stated, we cannot accurately determine. It may be interesting to many of our readers, to give a comparative analysis of albumen—the only likely material that the cotton could draw from blood—and one of wool, as derived from the sheep. It is as follows:—

	Albumen.	Wool.
Carbon	53·5	50·7
Hydrogen . . .	7·0	7·0
Nitrogen . . .	15·5	17·7
Oxygen . . .	22·0	24·6
Sulphur . . .	1·6	
	99·6	100·0

The albumen in the above is stated at ·4 short; and this consists of phosphorus, in union with lime, as the phosphate. It will hence be perceived that no very essential difference exists between the ultimate analysis of the albumen and wool; and hence why we speculate on the possible animalising power of that constituent of blood or dung on cotton, in increasing its dye-taking and retaining properties.

Urine is valuable to the dyer, the scourer of wool, and others, through affording a considerable quantity of the alkali, ammonia, as it putrefies. After exposure to the action of a warm atmosphere for a day or two after voidance, it undergoes decomposition, and the urea which it contains becomes converted into carbonate of ammonia, which, by further decomposition of an accidental nature during the process, gives off fumes of ammonia. In this condition it is a cheap and useful scour for wools; and, in many respects, is much more safe than either pearlash, soda, or soap, because any excess is readily dissipated by heat, owing to the volatile nature of the ammonia. It is also much employed, as thus produced, to render soluble the colouring matter of lichen dyes, such as litmus, cudbear, crottel, &c. These will only retain their blue colour in the presence of an alkali; for, as we have already noticed in describing them, under the head of Dye-stuffs, acids, or even acid vapours, at once convert these delicate blue shades to a bright red.

It is a singular fact, and one which may be interesting to the practical man, that urine is capable of producing some most beautiful purple colours, as evinced in the production of murexide by the action of nitric acid and carbonate of ammonia in succession on uric acid, a bye-product of urine. Equally singular is it that this excretion also contains aniline, derivable, as we have already stated, from indigo; and that we shall shortly describe at some length, as a product of waste gas liquor. It would cause us to enter too deeply into theoretical chemistry here to show the interesting connection that subsists between materials of our dye-houses and the products of animal life. They are exceedingly singular and interesting; and to their study by the practical chemist, the dyer owes the discovery of the beautiful aniline colours, to which allusion has just been made—a discovery equally of the highest scientific value in the laboratory, as it has, and will be, in our arts, manufactures, and commerce.

We have thus given a general description of most of the materials of the dyer, drawn either from the mineral, vegetable, or animal kingdoms. It is really a most curious circumstance, that the art of colour-production and ornamentation should result from so many sources, and so numerous and intricate processes. We cannot help contrasting here the hand of Nature with the hand of man in the production of colours for such purposes as that of pleasing the eye. In our commonest flowers we may see several colours in the same object or the same plant; as, for example, in the major convolvulus, or the equally well-known fuchsia. We cannot trace how it is that these beauties are so perfected; how these colours are blended or contrasted without mixture; in a word, how, in the same flower, so many different colours are simultaneously produced. If we would imitate them in the least degree, we have to go through numerous and difficult processes, and yet arrive, with all our best attempts, at a point infinitely below the perfection of nature, which seems to produce its results spontaneously, and without effort. But so it is with all the works of man: we may aim, but we never arrive at that perfection which animated existence, in the forms we have alluded to, constantly presents to us as objects of contemplation. It is this attempt to imitate that stimulates progress in every branch of art; and the nearer we get in producing a semblance of our natural model, the more we are tempted to exert our powers in attaining greater excellence.

Colours obtained from Coal.

One of the most interesting discoveries of this century has been that of extracting colours, capable of use in dyeing, from certain kinds of coal; and, as we have previously stated, this has resulted in an almost entire change in the various processes of dyeing.

Hitherto we have chiefly described such dye-stuffs as are attainable from plants directly, or by aid of insect life, as in the cochineal, lac, and kermes; and these sources of colouring matter have been familiarly known for some thousands of years; for the earliest history of man affords us accounts of the art of dyeing. It was re-

served for the present day to find, in the most unlikely of all sources, colours that far exceed, in their brilliancy and permanence, any previously known to man.

That coal is of vegetable origin is an opinion now universally agreed in by all competent judges of the matter. Frequently we meet with fossil plants as perfect in their form, in respect to leaf, stem, &c., as if they were still growing. The stems of trees of great size, indeed, have been discovered completely converted into coal. But it is chiefly to the fern tribe of plants, as far as we can judge, that the formation of the coal, in this country at all events, is due. In the carboniferous era—that is, the period at which the plants flourished from which our coal has been formed—ferns must have been exceedingly more abundant, both in quantity and variety of species, than at the present day. At least three times as many species have been found, fossilised as coal, than now grow in Great Britain.

A careful chemical analysis of coal, also shows that it must have been of vegetable origin, for it yields chiefly carbon, united with comparatively small quantities of oxygen and hydrogen; and, in certain cases, nitrogen—apart from various mineral matters, such as alumina, iron, sulphur, phosphorus, arsenic, &c., that must be considered as simply accidentally, but more or less universally, present. The fact of iron and sulphur being met with in coal, also indicates its vegetable origin, as most of the fossils, constituted of iron pyrites, and so abundant in the Isle of Sheppey, at the mouth of the Thames, are, doubtless, the result of the replacement of vegetable substances by those elements.

There is nothing, however, taught us by chemical analysis that would lead to the supposition of coal being capable of producing colouring matter. Some of our readers may have met with the ridiculous account, some time ago largely distributed, that the first suggestion that led to the discovery of coal colours, was made by the colours afforded by tar dropped on the surface of water. It is true that a thin film of tar on that liquid affords the most beautiful colours. But this is simply due to the fact, that tar becomes of such extreme thinness, as to only be capable of reflecting certain colours to the eye, dependent on the thickness of each film. The same result may be produced by the soap-bubble, which, when first blown, gives a red tint; but, as it gets thinner, gradually affords orange, yellow, green, blue, violet, and all intermediate tints, till at last it appears black, being then too thin to reflect light at all. Similarly, if we press a double convex lens on a piece of plate-glass, the same series of colours are afforded, called Newton's rings; and the polariscope, as already explained, gives similar results. It is evident, therefore, that the simple production of colour from tar, in the manner already indicated, has no connection whatever with the production of coal-dyes; and the first discoverer of them might just as well have expected to find yellow soap, or a glass lens, in a lump of coal, as to have had thus suggested to his mind the existence of colouring matter therein.

Like all other discoveries of importance, that of the coal-dyes was the result of scientific induction, exercised on previously known facts. We are not aware of any really beneficial result that has arisen from the application of science, which could properly be called accidental. An old legend (for we cannot call it better in respect to its deserts) accounts for the discovery of the laws of gravitation by Newton, as having resulted from his "accidentally noticing the fall of an apple from a tree." Now, since the days of Adam, apples, when ripe, have had the same habit; but only one Sir Isaac Newton has existed. Similarly, all our great additions to scientific laws have been seed falling on good ground, bearing fruit "an hundredfold."

In respect to the production of dyes from coal, we may briefly give some account of the various products that arise from its dry distillation. The first result of heating coal in the gas-retort, is to drive off the uncombined water that condenses in the ordinary mode of gas-making in the hydraulic main. As the heat is increased, numerous volatile products are given off, and, with few exceptions, are condensed. The permanently gaseous portion consists of various "hydrocarbons;" that is, gases composed of hydrogen and carbon only, but in various proportions. The most important of these is "olefiant gas," to which the illuminating power of our coal gas is chiefly due. Besides this, is the "light carburetted hydrogen," similar to what is called "marsh gas," given off, at certain seasons of the year, from large extents of land covered with decomposing vegetable matter, and, in fact, chemically passing into the condition of coal; carbonic oxide, an inflammable gas, composed of oxygen and carbon, and well known in producing the blue flame in our domestic fires, brick-kilns, &c.; carbonic acid gas, which we observe as producing the gas-bubbles of beer, champagne, and other effervescent liquors; and some others, to which we need not direct attention.

But of most importance are those products which are condensible, which include ammonia; some compounds of cyanogen that may be used in producing Prussian blue, and for other purposes; tarry matter, naphtha, and some naphthaline compounds, &c., &c. These are collected in the liquid state, being more or less condensed by the water in the main. Chemically speaking, these are mostly compounds of hydrogen and carbon, varying in the proportion of each element that they contain—not accidentally, however, but according to an invariable law, which the scientific chemist recognises as pervading all compounds of what he terms an organic nature.

By distillation of these mixed products, ammonia, as the most volatile, is first obtained; and it is a very valuable product for a variety of purposes. The pungent odour of the lady's smelling-bottle; one of the most valuable manures for the farmer's use; and the alkali that is used to scour wool, are all found in this first product of gas-tar distillation. Naphtha

next passes over; and within this is benzole, which we may consider as the basis of our coal-tar dyes. It exists in coal-tar naphtha to a varying extent, and may be separated from it either by distillation, or by exposing the naphtha to a temperature equal to the freezing-point of water. This *Benzole* has a smell much resembling smoke or gas, and is now commonly sold as a substitute for turpentine; as a solvent of india-rubber; and is largely used to clean gloves, silks, &c., by those who comprise dyeing and cleaning in the same business.

By acting on the benzole with nitric acid, we can obtain a compound called nitrobenzole, which has an odour resembling that of bitter almonds; and, indeed, can be substituted for that liquid in confectionery, scented soaps, and other similar purposes. Strange to say, that a vegetable product, well known as gum benzoin, can also afford benzole; and, still further, the chemist recognises a direct relation between this and the bitter almond oil obtained from the fruit of the almond tree, cinnamon oil, and some other compounds that we need not at present allude to. In fact, their chemical constitution is so analogous in each case, that, by the law of substitution, as it is termed in science, we can at once see the whole of these compounds alternately separated in nature, yet completely joined together in their philosophical aspects. To the man of science this fact is of infinitely greater importance than the discovery of the aniline dyes; but, as we are addressing the practical man alone, we must not dilate on this subject.

On adding nitric acid to benzole, a violent action takes place; and when this has ceased, a yellow-coloured liquid results, which is the nitrobenzole that we have just alluded to.

We here notice the addition of another element to those constituting benzole—namely, nitrogen; for benzole only possesses carbon, hydrogen, and oxygen; hence its chemical character is completely changed, and, consequently, its physical characteristics also.

Aniline is contained in the coal-tar liquor in but small quantities. As already stated, it is found in indigo, and even in human urine; but all these sources would be far too expensive to permit of its extraction for commercial purposes. We can, however, by the action of acetate of iron (see *ante*, p. 112) on the nitrobenzole we have been describing, and by other methods, convert it into aniline; and this new compound, consequently, may become the base of the various beautiful colours to which we have frequently alluded.

Aniline, in part, partakes of some of the properties of an alkali (see Potash and Soda, p. 381, *ante*); but it does not change yellow vegetable colour to that of a brown tint, as potash, soda, and ammonia can do. Prepared either by the acetate of iron, as just stated, or from the nitrobenzole dissolved in alcohol, and treated with ammonia and sulphuretted hydrogen until all sulphur ceases to be precipitated, the liquid being distilled with caustic potass, aniline is produced as a thin colourless liquid, having an odour somewhat resembling that of wine, and an aromatic taste. It is soluble in water; but especially so in alcohol (spirits of wine) and ether; hence the occasional use of the "spirit" in effecting its solution, in certain forms, for dyeing purposes.

In a scientific point of view, aniline presents many peculiarities and analogies; and its examination, and the fresh combinations that have arisen from its discovery, have given rise to an extensive series of results, that have been termed substitutions of the aniline series; but into the discussion of these it will be beyond our purpose to enter, because it would involve, on the part of our readers, an amount of chemical knowledge that, in writing these pages, we presume they do not possess.

The colours that have been obtained from aniline, in various modifications, embrace most of those previously procured from dye-stuffs of a vegetable and mineral nature; as, for example, various shades of red, blue, and all intermediate tints. Amongst the most important are the following:—

Magenta, a well-known and highly popular colour, is obtained as a dye-material by acting on aniline by the bichloride of tin (see *ante*, p. 114). Violent action ensues on their mixture. After some time, the heat generated raises the liquid to a boiling heat, when a deep red, but, apparently, a black liquor, from the depth of colour, is produced. By the action of nitrate of mercury on aniline, a similar result is afforded. The dye-material is partially soluble in water and alcohol, but insoluble in ether or naphtha.

Emeraldine, or aniline green, is the result of the action of chlorate of potash upon a solution of aniline in hydrochloric acid; and hence the oxidation of the aniline is effected (see our remarks on the use of chlorate of potass in oxidising protosalts of iron, at p. 117, *ante*). Violine is produced by oxidising aniline, which is effected by first heating two equivalents of sulphuric acid with one of aniline and water, forming a sulphate of aniline, and decomposing this by means of the binoxide of lead. The purple liquid resulting from this is boiled with potass, when the colouring matter is precipitated. To purify it from any extraneous matter, it is washed with water, and dissolved in tartaric acid. After evaporation, it is precipitated by an alkali, and a solution of alcohol (spirits of wine) may then be made of the precipitate, which affords a bronze-coloured powder on the spirits being evaporated. Roseine is prepared also by the action of the binoxide of lead on the sulphate of aniline; two equivalents of the binoxide being employed to one of aniline. The mixture is boiled for some time, and, after evaporation, the dye may be obtained as a precipitate by the addition of an alkali. It is soluble in water, but not in naphtha, and affords a beautiful crimson colour as a dye. A rich purple dye is obtained from aniline by mixing an equivalent each of the sulphate of aniline with the bichromate of potass (see *ante*, p. 113). The black precipitate is purified by coal naphtha from all resinous matter, and then dissolved in spirits of

tions—as, for example, sulphuretted hydrogen, almost always present in them—should be kept from ascending into the dye-house. We have already stated that the various salts, liquids, &c., used in dyeing, have a tendency, when decomposing by air, &c., naturally to produce this gas; and whenever it comes in contact with metallic colours it must injure them, for with all the metal-salts used in the dye-house, it produces a brown or black sulphide. The degree of this either more or less injures the brilliancy of colour produced from metallic solutions, but especially in the case of lead. Even gases may be instantly produced by allowing two vats to be emptied simultaneously; as, for example, one of acid, or "sour," and another of waste chloride of lime. In such an instance abundance of chlorine would be generated, which would mix in the atmosphere of the house, and certainly injure delicate colours. We only mention such instances as illustrating many others that may occur through thoughtlessness or negligence.

The general arrangements of a dye-house, in respect to heating liquors, baths, &c., must, of course, be left to the judgment of those who superintend the general operations; and it is wise, at times, to defer to a little prejudice in this respect. Many persons prefer "fires" under each "copper," in place of using steam; and occasionally, or, as we may say frequently, this plan has its advantages. We learnt an excellent lesson from an engineer in our employ, in the following manner. It was a custom, on our part, to trust this man whenever he made up his mind to "think;" and *his* habit was to sit quietly, perhaps for two or three hours, until he had matured a plan. Generally we found his practical views of greater value than those we entertained theoretically; and, on this ground, we, in all charity, give the fullest license to those who prefer direct heating by "fire" to steam-heat. As to the economy of the two methods, there can be no doubt that it is in favour of steam-heat. In respect to convenience, this becomes a question more of an accidental than any other character.

If the method of driving steam into vats or other vessels be adopted—that is, sending the steam directly into the liquor—certain precautions should be observed. For example: if an iron pipe were used for warming a solution of chloride of lime, it would be destroyed in a few days; hence it is advisable, in many cases, to have the whole of the pipe immersed in any liquor heated by steam, made of lead, which, as a rule, of all other metals, is least acted on by chemical agents. Lead, if tolerably pure—and in the form of lead pipe it must be, because any alloy, or accidental admixture of any other metal, would destroy its tenacity—is not, under ordinary circumstances, acted on by sulphuric, nitric, or hydrochloric acids. The acetic alone is to be guarded against in any of its forms in which we may include pyroligneous acid (see *ante*, p. 110). It is true that some difficulty occurs in "making a joint" between a brass cock (which should be always used, with a deep thread) and a lead pipe. Its own weight often breaks such a joint; but by proper care and judicious supports, such accidents may be prevented. We used to adopt the plan of bending the pipe horizontally to the extent of about four inches from the joint, and then supported the pipe, hanging into the vat, by means of a strong copper (not an iron) staple.

The usual effect of sending steam directly into any vessel filled with water, is that of producing a great amount of vibration in the first instance, owing to the formation of a vacuum, due to the condensation of steam in the conducting-pipe. Of course a great noise is thereby occasioned; and, as Mr. Grove, at a recent meeting of the British Association, at Nottingham, remarked, whenever there is noise there is loss of power. When a dye-tub, or other vessel, is so heated, an immense amount of vibration is caused; and if iron hoops surround the vessel, it is more than probable that its destruction will not long be delayed.

Impressed with ideas of economy, we, at one time, used some sherry and palm oil casks as bleaching vessels; and, neglecting the precaution we are now urging on our readers, adopted steam as the heating medium, in the manner already stated. We had soon occasion to repent of such false economical plans; but, to our knowledge, others have followed the same evil ways; and we can only hope that "a word to the wise" will be sufficient.

The construction of tanks for the dye-house, if the pecuniary means of the owner permit, should be always directed by motives of ultimate, rather than apparent present, economy: our own folly may thus serve as a warning to others. Good pine, in length of nine to twelve feet, with a breadth of from nine to eleven inches, and a thickness of about three inches (a usual standard), forms an excellent material for such purposes. As a rule, no chemical action can take place between any dye-stuff and the sides of the tank. The ends should be carefully morticed in; and if iron braces be used, they should be driven quite through the centre of the wood at each end and the bottom. Tanks so constructed will last for years. The external portion may be pitched or painted over; but the inside is best left in its "first estate." The length, &c., of the vessel, of course, must be left to the judgment and requirements of those who have to use it. In the end, however, a substantial arrangement of the kind will be the most economical. So-called cheapness, in all matters connected with chemical operations, generally turns out to be dear in the end.

We have ventured on giving such practical hints in respect to vessels intended to hold liquor. We may now pass on to consider other operations, such as washing, scouring, wringing, drying, &c., by mechanical methods.

It has been already stated, that cotton goods are not easily wetted by water unless bleached. This is due partly to the presence of a resinous matter; to atmospheric air attached to their surface; portions of grease, &c. Mere boiling in a solution of either pearlash or soda, or even lime,

wine. By distillation the dye is left as a mass of a bronze colour. It is readily soluble in spirits of wine, and less so in hot water; but insoluble in ether or naphtha. A fine blue dye is obtained by heating one part of bichloride of tin with about two of aniline to a temperature of 350°, in a closed vessel, for about thirty hours. A blue substance, soluble in water, spirits of wine, naphtha, and acetic acid, is afforded, technically called the *Bleu de Paris.*

Picric Acid, already mentioned, may be reckoned, indirectly, as belonging to the aniline series of colours, for it may be obtained from aniline by the action of nitric acid; also from silk, indigo, carbolic acid (its usual commercial source), and from other substances, by the same action. It completes, if we may so say, the series of dyes, which, directly or indirectly, from coal-tar, or the liquid obtained during the dry distillation of coal, affords us every colour of the spectrum, and all their intermediate shades for dyeing purposes.

The preceding are some of the most important colour-products of coal, although many more might be enumerated—upwards of a score, at least, having been discovered. They have, and still are, the subject of patent rights; and hence their preparation and sale are confined to those holding licences from the patentees. The processes for obtaining each have been varied; for it must be borne in mind, that aniline, although a compound of four elements—carbon, hydrogen, oxygen, and nitrogen—acts in all respects as a simple substance; that is, such as we find in the metals, and other bodies, that are deemed by chemists to be elementary in their nature. It can form an oxide, salts, &c.; and is hence subject to the action of acids, and oxidating agents, by which, in fact, its numerous colour-giving properties are educed.

The methods of dyeing by aniline colours are extremely simple in respect to wool and silk. Generally, these materials at once take the dye by simple immersion, either in an alcoholic solution diluted with water, or in one of that liquid when the dye is soluble therein. Hence the tar-dyes have got into even domestic use, so little difficulty is there in making them available. Certain measures are requisite in managing some of the dyes, however, on the large scale; and these we shall have to notice when we enter on the practical operations of the art in respect to colours obtained from this and other sources; our object here being only to give a general outline of the nature of coal-tar dyes, and of the peculiarities that distinguish them from those of a purely vegetable origin. Cotton, in an unprepared condition, does not permanently take these colours; but by giving it a "coating" of tannin, and other processes, it may be so prepared as to take and retain them in a manner almost equal to that noticed in respect to wool and silk. The details of such processes we shall enter into hereafter.

It will be noticed generally, that the aniline dyes are usually most soluble in spirits of wine (alcohol); and in this, and many other respects, those of our readers who are acquainted with chemical science, will recognise much analogy between them and alkaloids. These we may explain as the "principles" of plants; such as morphia from opium, strychnine from the nux vomica bean, quinine from cinchona bark, &c., &c. All these, like aniline, have an alkaline nature; they are all composed of four elements—carbon, hydrogen, oxygen, and nitrogen; and are generally but slightly soluble in water, although readily so in alcohol. Many other analogies might be pointed out; but we must pass them by as foreign to our subject.

We have now described nearly every material employed by the dyer in his trade, whether drawn from the mineral, vegetable, or animal kingdoms, including the coal-tar dyes, which last promise, in a great measure, to supersede all others. We may now turn, accordingly, to describe some of the implements of the trade, as employed at large and well-appointed works.

The great requisites of the dye-house are—an abundant supply of clean soft water, a question to which we have already directed attention at p. 90, *et seq.*, in respect to chemical purity; the best possible drainage; and means for quickly getting rid of the abundance of steam that is constantly passing off the vats, coppers, and other vessels in which the dyeing processes are carried on. It is of great advantage to have such an establishment near a river, from which, at its upper part, the supply of water may be drawn; whilst at the lower end, in respect to the works, the waste water, &c., may be got rid of; for next in importance to an abundant and good supply of water, is that of getting rid of the waste.

An excellent method, that we have occasionally seen adopted, and which always should be when possible, is to have a channel in the middle of the floor of the dye-house, by which the waste liquids are carried off to the drain, from the vessels on either side of it. The pavement from these should gradually fall towards the channel, and thus the contents of the vat are readily disposed of by simply pulling out a plug at its side or bottom, and letting the liquor run away.

A common source of great annoyance, that will frequently occur in establishments where the drains are narrow, is their stoppage, from pieces of cotton, &c., that will gradually accumulate at all angles or bends. Some years ago, we had a drain, twelve inches either way, completely stopped in this manner, which entirely prevented bleaching and dyeing operations for some days. The waste from the chloride of lime, with little pieces of cotton, flowed down with the water; but the solid matter gradually accumulated; and, at last, the chloride becoming converted into the carbonate of lime, entirely closed the channel. Hence bends, and narrowness of drains or sewers, are often sources of great inconvenience. It is equally essential that they should have a good fall; that is, a considerable and constant decline from the dye-house to the main sewer, if such means is the only one by which the dye-house gets cleared of spent liquor, &c.

Another point of importance in large drains is, that gases highly prejudicial to dyeing opera-

removes all these hindrances to the reception of colour, so far as they affect it. In all branches of the art of dyeing, abundant washing in water is essential; and, formerly, this was a most laborious part of the business. An ingenious invention, called the dash-wheel, has overcome the difficulty, and much more effectually produces the cleansing of yarn goods, &c., than the old method.

The dash-wheel consists of a hollow cylinder, or drum, six or eight feet deep (vertically), and about three feet in diameter (horizontally). It is separated inside into four or more compartments, intended to hold the goods. When these are placed in the wheel, it is turned round by steam-power, and water is admitted abundantly into it. Thus a constant current of liquid permeates all parts of the goods, and they are thoroughly cleansed.

A modification of this arrangement is equally serviceable for drying purposes. In the drying or wringing-wheel there is also an external cylinder, like the preceding; but inside is another drum, or cylinder, perforated all over its periphery with holes. After the wet goods are placed within, it is driven round at a very rapid pace; and thus all water is extracted from the goods by the action of centrifugal force. This ingenious and highly effective method is literally only an adaptation of the method of drying mops by "trundling" them; for, in that simple operation, as the mop rapidly revolves in the hand, the water flies off by virtue of the same centrifugal force as operates in the drying-wheel.

In dyeing yarns, it is frequently desirable to extract, as much as possible, all extraneous mordant solution, because all of this that is not

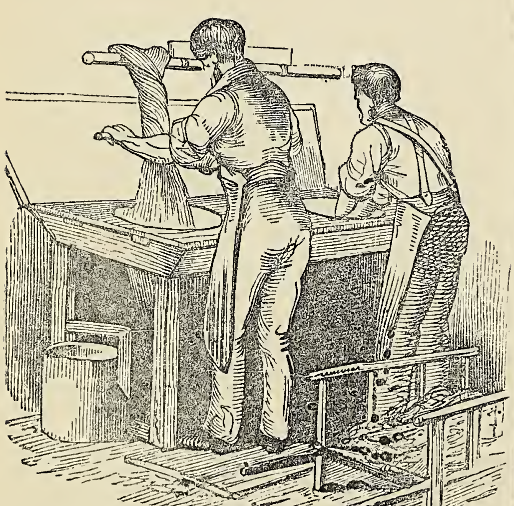


Fig. 88.—Wringing Apparatus.

permanently and intimately attached to the fibres of the material, is not only waste in itself, but also causes waste when admitted into the dye-stuff, or bath. The same observation, of course, holds good in reference to woven goods; but these are generally passed between rollers, to free them from superfluous liquor. For yarns, the wringing-post is a necessary implement in the dye-house. It is generally formed of an upright, from which horizontal bars extend, on which the yarn is hung. All other portions are then twisted round, so as to press out all liquid as far as possible. The preceding cut represents one of these wringing arrangements affixed over the dye-tub.

In the operations of both dyeing and bleaching, all the preceding methods are employed; the great object, in each case, being to introduce as much as possible the liquors to all parts of the goods at one time, and, at another, to remove them as completely as can be effected. Another and very ingenious plan for the first purpose, and especially adapted in dyeing and bleaching woven goods, such as calicoes, is as follows:—The piece-goods, on being received from the manufacturer, are tacked together, end to end, in one continuous web. This is carefully folded, so that the cloth may be regularly withdrawn without being creased. One end of the web is then passed over a roller that is fixed above the first vat, or tub, in the series of operations. In this vat are two rollers fixed at the bottom, and beneath these the cloth is passed. It is then put over a roller revolving over the second vat, and passed beneath two rollers at the bottom of this, as in the first vat. Any number of these may be arranged side by side. The annexed cut represents this most ingenious and effective invention, by which bleaching or dyeing may be

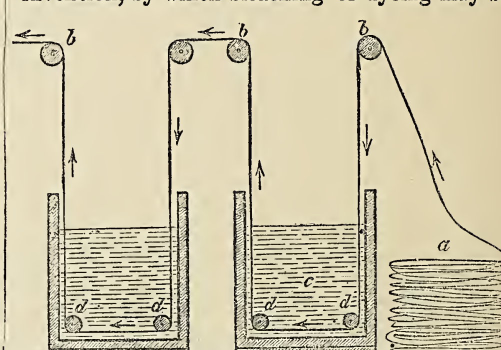


Fig. 89.—Bleaching, etc., Vats.

a, the calico as received from the weaver; *b*, the roller over which it passes into the first vat, *c*; thence it proceeds in the direction of the arrows, guided by the rollers inside (*d*) and outside (*b*) of the vats, through each successive one, until the entire operation is completed.

carried on continuously for any length of time, with scarcely any attention being required on the part of the workman. By the addition of hollow metal cylinders, filled with steam, and placed beyond the last vat in the series, the cloth can be simultaneously dried.

In calico-bleaching, previous to printing, we have seen this method much adopted; and, with the exception of paper-making, we can hardly

instance any invention so ingenious, so saving of trouble, and generally effective. The visitor to some large calico-printer may, on his entrance, notice the gray cloth delivered at the door; and whilst he is engaged in fully inspecting the works, the same goods, by means of the plan we have described, will have passed through the leys, to remove resinous and greasy matter, the souring to remove the iron, the bleach-vat, &c., &c.; and he will find them beautifully white, dry, and ready for printing operations before he leaves. Of course steam-power is necessary to move the calico onward; but little force is required; whilst all manual labour and expense is saved—a matter of great importance to large calico-printers, whom we have known, on certain contracts, to sell their goods at a *fraction of a farthing* per yard of profit!

We may here notice that, of late years, one great reason of the diminution of price in cotton and other goods, has been such applications of steam-power, and various mechanical appliances, to operations in which it was previously considered essential that manual labour should have been adopted. A visit to our manufacturing districts of Lancashire, Yorkshire, Glasgow, and its neighbouring towns, is well worth making, for the purpose of studying the vast amount of ingenuity thus expended in economising time, money, and human exertion. In many establishments the floors are laid with rails like a railway, and trucks are thus easily run from one part to another by boys, although heavily loaded. The "hoist" is another ingenious arrangement, by means of which goods and workmen may pass in a minute from the lowest to the highest floor of a building. In fact, a large manufacturing establishment of any kind, at the present day, is an embodiment of applied science in a great variety of forms; all of which, by the economy of time, &c., they effect, lessen the cost of production, and so place within the means of all classes, under ordinary circumstances, the power of obtaining decent clothing. This economy, in respect to dyeing and bleaching, has enormously increased. For example: we have before us a piece of a lady's cotton printed dress, having a red ground with white spots—a hideous production in respect to art; yet the dress cost, towards the close of the last century, a guinea and a-half. At this day, the same quantity of material, beautifully and artistically printed, can be bought for a fourth of the money; and hence four times as many persons can now be clothed with the same material as at the date to which we have just referred. Perhaps one of the most astonishing illustrations of this economy in our manufactures, is seen in the fact that we now import an immense quantity of cotton from India, and its indigo, with other dye-stuffs. These are brought to the shipping ports of that country by land-carriage at great expense. They then have to travel some ten thousand miles by sea to our manufacturing districts. Then, in spinning, &c., the cotton loses about 10 per cent. of its weight; and when woven, an additional loss occurs in bleaching. Yet it is dyed, or printed, and returned another ten thousand miles, to be worn on the bodies and backs of the very men and women who either picked the cotton from the pod, or collected the dye-stuffs by which their favourite colours have been imparted to it. No greater proof can be adduced of the enormous advantages which thus, nationally and socially, arise from our manufactures, which, whilst they enrich us, spread the means of comfort, decency, and therefore morality, over the whole world, civilised or savage.

We have now directed attention to some of the leading implements of trade of the dyer, and incidentally, also, those used by the bleacher, to whose operations we must shortly devote a separate notice. But before entering into the practical details of either, we may briefly describe two instruments that are of essential use in both trades—we mean the thermometer and hydrometer; the first being used to measure the temperature, and the last is employed to ascertain the specific gravity, or strength, of liquids.

The *thermometer* is an instrument of great use in the dye-house, provided its operations are carried on under scientific principles, because our power of extracting so-called "principles" much depends on the question of temperature. We know, for example, that it would be impossible to obtain from logwood any valuable matter, for any purpose, at the ordinary temperature of the atmosphere; whilst, at the heat of boiling water, such a result is procured with the greatest facility. Again, solutions, infusions, decoctions—or, in the technicality of the dye-house, the bath—are not procured, in all but rare cases, at temperatures lower than that of boiling water; because, whenever we use any substance from which a solid becomes soluble, *generally speaking*, a temperature as high as that of 212°, or that of boiling water at the atmospheric pressure of the sea-level, is required. It would be impossible, therefore, to make a good cup of tea or coffee, or, still less, some dye-baths, at the top of Mont Blanc. It is true that this is an extreme case, but it illustrates the principle at which we wish to arrive.

Again, the specific gravity of liquids (to which we shall, presently, have more particularly to allude) is much affected by temperature; because solids, liquids, and gases, greatly expand when they are heated beyond 60° or 62°, the average medium of temperature generally adopted in scientific matters. The ordinary expansion of the mercury, or spirit, in a thermometer, is sufficient to prove this fact. Indeed, we depend on this action as a measure of varying temperature,

The construction of a thermometer is very simple in theory, but requires great care in practice, when the instrument is intended for scientific observations. But even in the dye-house a much greater exactness is required than is generally to be obtained by using the common kinds of thermometers; and it is frequently an amusing illustration, to notice in the windows of shops where the cheap kinds are sold, a number, side by side, all "warranted" as accurate, and yet differing several degrees, even at ordinary

temperatures. Such articles are simply valueless for any purpose, except the amusement of scientifically-disposed children.

The thermometer consists of a glass bulb filled with mercury or spirit (but the latter are of no use to the dyer); and attached to the bulb is a stem, the rising or falling of the liquid in which enables us to measure relative temperatures, by aid of a scale externally attached to, or marked on, the glass. The latter kind is much to be preferred, because then the thermometer may be immersed in any solution, without affecting the material of the scale. Acid, and many other liquids in the dye-house, act on wood and metal: hence the value of a glass or enamel scale. The instrument is constructed by first filling the bulb, and a portion of the stem, with pure mercury. Heat is then applied to the bulb, so as to make the mercury completely fill the stem, the top of which is then melted; and thus an air-tight sealing is effected.

The next step is that of graduation; for which purpose two fixed points are desirable, and those are—that of water on the point of freezing, or ice in the act of dissolving; and that of the boiling-point of water at the sea-level, and at an average pressure, indicated by the barometer, of thirty inches elevation of the mercury in the tube. The reason of this adjustment according to the pressure of the atmosphere, is, that as we ascend above the sea-level, the boiling-point of water decreases simultaneously with the pressure. Thus, if the latter was 0, then water would boil at a temperature not greater than that of our blood. Hence, as we have already remarked, on the other hand, water under pressure greater than that of the atmosphere, or about fifteen pounds on each square inch, requires a higher temperature before it will boil; and this is in a certain ratio with the increased pressure.

Having chosen these two extremes of the scale, the freezing and boiling point of water, three systems have been adopted for intermediate graduation—namely, that of Fahrenheit, by which a total of 180 degrees, or 180°, as it is usually written, exists; that of Celsius, but generally called the centigrade system, in which 100 divisions or degrees are employed; and, lastly, that of Reaumur, wherein 80 divisions or degrees correspond to the two previous modes of dividing the scale.

In this country that of Fahrenheit alone is used; and the reader will understand that, throughout this work, that system alone has been adopted.

It will be unnecessary to give the dyer any directions as to the tests that we have for ascertaining the accurate graduation of thermometers. His best plan is to purchase a good one at a respectable maker's; and the laws of construction, just briefly described, will give him sufficient information to understand the principles on which accuracy is ensured.

The *hydrometer* is an instrument for ascertaining the relative specific gravities of liquids. By this term, we mean the relative weight of any bodies, whether solid, liquid, or gaseous, when of equal bulk. For example, if we take a cubic inch each of air, water, and lead, we should find their weight would greatly vary. The water would weigh about 840 times as much as the air, and the lead nearly $11\frac{1}{2}$ times that of the water; and these weights, relating to a certain fixed standard, express what we term the *specific gravity* of any body.

As we have already stated, these relative weights are, to a certain but invariable extent, dependent on temperature; because, as a body expands by heat, it occupies more space than it did at a lower temperature. On this fact, indeed, does the action of the thermometer depend, the expansion of the mercury indicating an increase of temperature. The standard temperature has been generally fixed as at 62° Fahrenheit, although 60° is often quoted for the same purpose. But, to the dyer or bleacher, two or three degrees above or below this standard will not become a question of much practical importance. Although, as a rule, the specific gravity of liquids alone is worthy of attention in matters relating to dyeing and bleaching, still, as the principle of ascertaining it is equally involved in that of solid matter, and may occasionally be of use, even in that respect, to the practical man, it may not be out of the range of the purpose of this subject to give definite, although brief, instructions as to the usual methods of ascertaining the specific gravity of both solid and liquid bodies.

If a body be first weighed in air—say, for example, a piece of lead—and this be subsequently immersed in a vessel of distilled water whilst it is suspended from the pan of the scales by means of a horse-hair, it will be found that the lead will weigh less, when so immersed in water, than it did in the air. If, again, a vessel be exactly filled with distilled water, and the piece of lead, after being weighed in the air, be immersed in it, of course a certain quantity of water will overflow the top of the vessel, equal in bulk to the lead so immersed. Now, if the bulk of lead so introduced into the vessel filled with water, weigh exactly as much as the bulk of water it displaced, we should say that the specific gravity of the lead and water were equal. If the experiment, however, be carefully performed, and, as near as possible, the water displaced be weighed, it would be found that the liquid would only weigh between one-eleventh and one-twelfth part of that which the lead weighed that was introduced into it.

A very simple rule, therefore, arises from the consideration of this fact, in reference to discovering the specific gravities of solids heavier than water. It is this—

First, weigh the body in air. Next, suspend it from the bottom of the scale by means of a horse-hair, and immerse in distilled water, at, as near as can be, a temperature of 60°. Weigh it whilst so immersed in the water. Divide the weight in air by the difference between that and the weight in water, and the result will give the ratio of weight between the body and water; or, in other words, the specific gravity of the

body in relation to water will be obtained. Therefore the loss of weight, caused by weighing the substance in water, becomes the divisor; the weight in air the dividend; and the quotient gives the specific gravity.

In estimating the specific gravity of liquids various methods are adopted; and this question, as already remarked, is of the utmost importance to the dyer; because there is scarcely any dye-stuff that forms a bath, infusion, or decoction with water, that does not thereby increase the specific gravity of that liquid. Hence the specific gravity of a bath becomes an indication, under certain restrictions of temperature, &c., of its strength. In respect to leys, chloride of lime, &c., such a method of ascertaining strength may generally be depended on, provided the articles employed are of average, or, perhaps rather, "honourable," commercial purity.

Water, as we have already stated, is always chosen as the standard of specific gravity for solids and liquids of greater or less density than itself. Hence we express such specific gravities in relation to water, assuming the latter, as a rule, to be unity. Thus, whilst a certain bulk of water weighs, say 1·000, or one (for the decimal has been here so pointed off), lead weighs, say 11·5, or eleven and a-half times as much; whilst sulphuric acid, or oil of vitriol, should, if strong, weigh about 1·845, or one and $\frac{845}{1000}$ times as much as water. From considering this method of estimating specific gravities in relation to liquids, we arrive at a very simple way of ascertaining them; because it is evident that, if a bottle holds exactly 1,000 grains of pure water, at a temperature of 60° or 62°, and when filled with sulphuric acid it weighs 1,845 grains, the specific gravities, or relative weights of the two liquids, would be as 1,000 is to 1,845. But to diminish the number of whole "numbers," we use the decimal notation, and say that the specific gravity of the acid is 1·845; for it can then, evidently, be compared with the whole numbers that represent the specific gravity of solids, always so reckoned. Thus the specific gravity of sulphuric acid is to lead as 1·845 is to 11·5 nearly.

We may, therefore, readily ascertain the specific gravity of any liquid by weighing it in a vessel holding exactly 1,000 grains of distilled water; and whatever the liquid weighs, more or less, in relation to the same bulk of water, at once expresses its specific gravity. And if we shift the decimal point in the four figures (in all practical cases in the dye-house), so that the standard shall represent, in respect to water, one instead of one thousand, the specific gravity of the liquid in question will be at once shown. Thus, the specific gravity of oil of vitriol, or sulphuric acid, will be 1·845, or greater than water; whilst that of proof spirit will be ·840, or less than water; that of various oils between sperm and castor oil, also lighter than water, runs from about ·890 to ·965.

But the method we have described would be too tedious for most practical processes. In the laboratory, where all apparatus can be found ready and convenient, this plan may be most properly adopted, because of its highly-possible exactness. More ready means are available for the dye-house, and other places, where more rough results are of use; and to these we will now direct attention.

The hydrometer, of which there are several kinds, is exactly suited for the purpose. Its most simple form consists of two hollow bulbs, the lowest and smallest of which holds mercury, which in weight is so adjusted that the air in the bulb just above it shall be so counterpoised that a certain part of the stem shall always float at one surfaace or level in distilled water, at a temperature of 60° or 62°. Thus, in the annexed cut (Fig. 13), A represents the stem graduated to some scale; B, the bulb filled with air; and C, that containing mercury as a counterpoise.


Fig. 90.

Now, it is evident, that if a liquid which is experimented on be lighter than water, this hydrometer will sink in it below, whilst, on the other hand, if the liquid be heavier than water, the hydrometer will rise in it above, the level of the mark 0, indicating that surface shown as the water-line by distilled water. Such an instrument, therefore, becomes a measure of the relative specific gravity of any liquids which may be tried by it. All necessity for weighing is done away with, and a ready, and tolerably accurate, means is afforded of judging of the strength of any liquids that may be employed in dyeing or bleaching. We may here incidentally mention that such an instrument has numerous applications. If used to ascertain the specific gravity of spirituous liquors, it receives the name of the spirit hydrometer, or alcoholimeter; if for sugar solutions, it is called the saccharometer; for ascertaining the value of milk, a lactometer; and so on.

But the graduation of such instruments varies; hence these numerous modifications, although the principles of the construction of all kinds are identical. For purely laboratory purposes, such as show the actual specific gravity in relation to water as unity should alone be used. One of these, for example, would indicate at once, on the scale, ·840, if placed in the best spirits of wine; 1·000 if in distilled water; and 1·845 in strong oil of vitriol; all other intermediate strengths being similarly indicated, according to the liquid in which the instrument is immersed. One instrument is not sufficiently extended in scale or range to denote many specific gravities above and below that of water; hence a set, each having a special range, should be provided for accurate results. A thermometer and a tall glass vessel are generally supplied with such a set; and their graduation varies from ·700 to 2·000, and rises at the rate of ·001, or the one-thousandth part of a degree of the scale.

In the dye-house, Twaddell's scale is mostly used; whilst that of Sikes's is in universal

employment for measuring the strength of spirituous liquors, especially in relation to the excise laws. Each ten degrees on Twaddell's scale corresponds to ·005, or five one-thousandths of specific gravity, in which water, as the standard, is reckoned as one, or 1·000. It hence follows, that by multiplying any number of degrees on Twaddell's scale by ·005, we get the specific gravity stated in relation to water, but must add the whole number, 1·000, to express it. Thus, supposing a sample of oil of vitriol indicated a strength, according to Twaddell, of 160°, then its specific gravity, according to the ordinary method of notation, would be—

$160 \times \cdot005 + 1\cdot000$; or it would equal 1·800.

On the other hand, we convert the ordinary notation of specific gravity by dividing it, less 1·000, by ·005. Thus, if we wished to know what Twaddell's scale would represent the above-named specimen of oil of vitriol, we should use the following method:—

$$\frac{1\cdot800-1}{\cdot005}=160^\circ.$$

It may be convenient to many of our readers if we give a skeleton table of ordinarily denoted specific gravities, compared with their equivalents according to the scale of Twaddell. In the left-hand column, the specific gravity in relation to water is given; and the right, the corresponding indication of Twaddell's hydrometer:—

Ordinary Standard.	Twaddell's Scale, in degrees.	Ordinary Standard.	Twaddell's Scale, in degrees.
1·000	0	1·525	105
1·025	5	1·550	110
1·050	10	1·575	115
1·075	15	1·600	120
1·100	20	1·625	125
1·125	25	1·650	130
1·150	30	1·675	135
1·175	35	1·700	140
1·200	40	1·725	145
1·225	45	1·750	150
1·250	50	1·775	155
1·275	55	1·800	160
1·300	60	1·825	165
1·325	65	1·850	170
1·350	70	1·875	175
1·375	75	1·900	180
1·400	80	1·925	185
1·425	85	1·950	190
1·450	90	1·975	195
1·475	95	2·000	200
1·500	100		

By referring to the above table, the practical man may readily convert the scientific estimate of specific gravity, as shown on the left hand, into that of the practical dye-house estimate given on the right; and hence many difficulties to those unused to arithmetical calculations will be avoided.

Occasionally Beaumé's method of graduating the hydrometer is used; but this occurs so rarely (that of Twaddell's being mostly preferred), that we need not give a detailed scale of this graduation, compared with that of the ordinary scientific notation. For liquids heavier than water, which are those only required, as a rule, to be tested in the dye or bleach-house, Beaumé's scale may be converted into that of the ordinary specific gravity notation, thus:—Divide 144 by 144, less the denoted degree of Beaumé, and the result affords the ordinary noted specific gravity. Thus, if we wish to convert 30° of Beaumé into the latter value, we have $\frac{144}{144-30}=1\cdot263$, the required specific gravity according to scientific notation.

Nicholson's hydrometer consists of a spindle, at either end of which a little tray or dish is placed. It acts, either in liquids heavier or lighter than water, by sinking to a certain point marked on the stem, which, in distilled water, would require, say, 100 or 1,000 grains, according to the construction of the instrument. Of course, in a liquid lighter than water, less weight than the 100 or 1,000 grains would be required to sink it; whilst in others heavier than water, more weight would be needed; and this decrease or increase becomes a ready measure of the specific gravity in relation to water, or between any two or more liquids that it may be desirable to compare with each other in that respect.

Another and very simple method of roughly arriving at the specific gravity of a liquid, and which may be easily and advantageously employed in the dye or bleach-house, is that of having a number of glass beads of varying weights, corresponding to different specific gravities that may be ordinarily required. These act on the following principle:—Any portion of a liquid, of the same specific gravity throughout its entire bulk, would float or remain at rest in any other part indifferently. Now if, in place of such portion of the fluid, a glass bead be blown, of such a bulk and weight as corresponds exactly to that of the liquid—or, in other words, having the same specific gravity as the liquid—it will float indifferently in any part of a vessel holding the fluid. Supposing this to be heavier than water, and water be added to it, of course the specific gravity would be lessened, and the glass bead or bulb would sink to the bottom of the vessel. If, on the other hand, the liquid was made more concentrated, then the bead would rise to the top. Hence its floating indifferently in any part of the fluid, is a sign that it has a precisely similar specific gravity. This method is much adopted in distilleries, &c.; and is equally useful for the dye-house. Sets of such beads, marked with their individual specific gravity, according to the scientific notation, may be obtained of most instrument-dealers. By using the tables and rules already given, their specific gravity indication may readily be converted into the scales of Twaddell or Beaumé.

With these remarks we conclude what must be termed the introductory portion of our work, in which we have endeavoured to explain the

principles and details of matters, attention to which is of great importance to the successful pursuit of dyeing as a business; but which we feel convinced, from an experience of a considerable period, have not received that careful attention which they deserve. The more we follow the teachings of science, the less chance have we of failure through what are called "accidents;" but which mostly occur through ignorance or prejudice. We next turn to consider the details of dyeing processes, prefacing them by a brief account of the progress of the art in ancient and modern times.

The Practical Details of Dyeing.

There is no branch of applied chemistry with which we are acquainted, in which the principles, laws, facts, &c., of the science are more completely involved than in that of dyeing; and in none is the precision of chemical science less regarded in respect to quantities, and other questions of weight and measure. Empiricism is generally the characteristic of its pursuit; or, in other words, each practical man, as a rule, conceives himself to be the best judge of the proportions in which each dye-material should be employed to produce a definite and satisfactory result in all kinds and conditions of colours.

There are, however, several reasons why such should be the case. In the first place, the choice of material is very extensive in the vegetable kingdom for many colours: for example, yellow, red, and blue—the last one being, perhaps, the most restricted of the three primaries. By using successive combinations of such dye-stuffs with suitable mordants, many varieties of shades may be produced, as we have already mentioned to be specially the case in respect to logwood as a dye-stuff. We have also seen that colours apparently quite opposite to each other—as red and blue from lichen dyes; yellow, orange, and black from yellow astringents, as sumach, fustic, quercitron, &c.; and red, to all shades of violet, from certain woods, as logwood, Brazil, &c.—may be readily obtained from similar sources.

Again, the quality of colour-production is not universally equal; for a plant may be too old or young to yield its best results for the dyer's purpose. It hence follows that, independently of intentional adulteration—as there are so many "accidents" in respect to vegetable dye-stuffs—we must make every allowance for the empirical character of the art.

It must be also borne in mind, that of all other arts, dyeing has been one which (with the exception of its aniline colours, that are of recent discovery) has depended mostly on blind experience for its practice and development. We were much impressed with the great progress that ancient nations, especially the Egyptians, must have long ago made, whilst, on two occasions, we witnessed the unrolling of mummies. Many of the colours, in portions of the cloth, had withstood the action of air and moisture for some thousand years. Could our modern dyers and calico-printers boast of hoping such a result in their colour-productions?

It would seem, according to a very good authority, whom we shall take the liberty of quoting (the late Mr. Barlow), that "the Egyptians are amongst the earliest nations of whose skill in dyeing we have any authentic account; but it is extremely probable that they derived the art from the Hindus, and other inhabitants of India, who state that they practised it from a very remote period: indeed, most of the ancient Arts and Sciences seem to have arisen in that quarter of the globe; and although, on account of the political and religious institutions of these countries, they never attained there any degree of perfection, they gradually spread from this source amongst other nations less fettered by prejudice, and more disposed to adopt whatever might be regarded as real improvements. The natural fertility of India, and the great variety of materials that it affords for cultivating the art of dyeing, were extremely favourable to its early progress; but religious prejudices, and the unalterable castes of society, as above observed, imposed restraints which interfered greatly with the attainment of perfection. It appears, indeed, that the art of dyeing cotton was in the same state when Alexander invaded the country as it is even at this day, their processes being still so complicated, tedious, and imperfect, that they would be impracticable in any other country, in consequence of the cost of labour they incur; in fact, European industry has far surpassed them in correctness of design, variety of shade, and facility of execution; and if we are inferior in the liveliness of some few colours, it is solely to be ascribed to the superior quality of some of their dyes, or, perhaps, to the length and multiplicity of their operations."

Much truth is involved in the opinions expressed by Mr. Barlow; yet we cannot but regret that, at the moment of this being penned, the same reproach, in respect to "the length and multiplicity of these operations," has equal application in our time. For example, we, a short time ago, placed in the hands of three practical dyers the problem to solve—of what quantities of dye-stuffs they would individually use for the purpose of dyeing a quantity of cotton yarn of a special shade of black? And as no question of personal or pecuniary interest interfered with the expression of their opinion; and, further, as the personal experience of the three varied from twenty to forty years, each then engaging in a profitable business, we naturally expected a reply or formula of something like uniformity from each. Instead of this, the quantities of sumach, logwood, iron liquor, &c., were absolutely discordant; and, speaking from some considerable and lengthened knowledge of the subject, we can only repeat, that, to a large extent, although we have greatly availed ourselves of the discoveries of chemistry, and have advanced our knowledge enormously in respect to the nature, quality, and properties of dye-stuffs, yet empiricism is the rule, and

scientific precision the exception, at this day, in the ordinary operations of dyeing.

It will naturally be retorted on us, that if we find fault with such methods (if they can be so called), we are in duty bound to point out such as are more precise in result. But this is simply impossible, because the art depends so much on mere mechanical processes, as affecting chemical results. A too lengthened exposure of yarn or goods in the vat or trough, must result in affecting both the depth and regularity of colour imparted. Heat, as we have already shown, has a similar effect, if not properly regulated. Irregular pressure in wringing, careless drying, and numerous other causes, entirely oppose and destroy the best effects that might arise from a precise application of those chemical principles on which dyeing depends; and until those who pursue it rise from the level of the human machine to that of human intelligence, in the general direction or operation of the dye-house, the ancient reproach against the Egyptians or Hindoos will be equally deserving amongst ourselves.

For this reason we have been careful, in the present work, to lay before our readers, in the preceding pages, *facts rather than opinions.* We have endeavoured to make it incumbent on every reader, practically engaged in dyeing, to study the why and wherefore of all he does. In our own opinion, if we could, in the following pages, give instructions so exact that all who read them might attain a great amount of success in dyeing, in respect to the quantity of material to be supplied, we should consider that the object of this work would be far less fulfilled, than in urging, as we have hitherto endeavoured to do, a scientific precision, so far as possible, in all operations. Remarking on this, and quoting only such portions of his remarks as suit our purpose, Lord Brougham has said—"To how many others does chemistry prove almost necessary. Every one must, with a glance, perceive that to * * * bleachers, and dyers, the sciences are most useful, if not necessary." Referring to a knowledge of principles, he adds—"Nor is it enough to say, that philosophers may discover all that is wanted, and may invent practical methods, which it is sufficient for the working man to learn by rote without knowing the principles. He never will work so well if he be ignorant of the principles; and for a plain reason: if he only learn his lesson by rote, the least change of circumstance puts him out. Be the method ever so general, cases will arise in which it must be varied, in order to apply; and if the workman only know the rule, without knowing the reason, he must be at fault the moment he is required to make any new application of it."

We thus notice the value of an intimate knowledge of the principles of any art, followed as a business, so far as assistant of practical operations. We may, however, with much advantage, urge on our readers engaged in dyeing, bleaching, or any other application of chemical science, another consideration, conveyed in the words of the same writer:—"But another use of such knowledge to handicraftsmen is equally obvious; it gives every man a chance, according to his natural talents, of becoming an improver of the art he works at, and even a discoverer in the science connected with it. He is daily handling the tools and materials with which new experiments are to be made, and daily witnessing the operations of nature * * * * in their chemical operations on each other. All opportunities of making experiments must be unimproved, all appearances must pass unobserved, if he have no knowledge of the principles; but *with* this knowledge, he is more likely than any other person to strike out something new, which may be useful in art, or curious or interesting to science." Referring to discoveries by chance (in connection with which we draw the attention of our readers to the remarks we have made in respect to this point, and the discovery of aniline colours, at p. 122, *ante*), he observes—"But, in so far as chance has anything to do with discovery, surely it is worth the while of those who are constantly working in particular employments to obtain the knowledge required; because their chances are greater than other people's of so applying that knowledge as to hit upon new and useful ideas: *they are always in the way of perceiving what is wanting or what is amiss in the old methods, and they have a better chance of making improvements.* In a word, to use a common expression, they are in the way of good luck; and, if they possess the requisite information, they can take advantage of it when it comes to them."

These quotations have been made especially for the benefit of those of our readers on whom falls the honourable appellation of workman, artisan, or any other term denoting that manual labour is an essential part of their calling. We earnestly, but respectfully, urge on them the due consideration of the advice tendered by one who had known, for nearly seventy years, what hard work means as well as any hard-working operative can do; and of whom it is related that, when one of our leading reviews was on the eve of being due for publication, but that a shortness of matter occurred, supplied nearly every "article" in the quarterly number (the *Edinburgh Review)* currently issued.

Early processes of dyeing, in respect to the Greeks and Romans, were in a crude state in the time of Alexander; but, as we have already stated at p. 98, they were well acquainted with the use of the insect *Kermes*, as a source of red dye, it being a native generally of Southern Europe, many parts of Asia, and Northern Africa. In the days of Pliny, the eminent naturalist, it was largely employed; and alum was well known in his time, but is a matter of question whether it was in any way used as a mordant; although, as stated at p. 95, *ante*, the general use of mordants was well known at that period. Madder, woad, dyer's broom, alkanet, walnut bark, and some species of the pod-bearing order, or *Leguminosœ*, were in use for dyeing purposes. Indigo seems also to have been known.

However deficient the ancients may have

been in respect to purely chemical knowledge (and we have no reason to believe that they possessed much of this), it is evident, from the remains of Pompeii, and evidenced by other sources, that they were capable of producing excellent dyes, and most permanent pigments. It is true there were greater advantages in their favour in respect to the purity of the air, and much drier atmosphere, which existed, and still exists, in Southern Europe, Northern Africa, and the Levant coast of Asia Minor, than we can boast of—circumstances highly favourable to the permanency of colour in any form. Still we must give the palm of merit to the Romans, and other nations, existent and partially civilised some two thousand years ago, for great practical ability in colour-production. History, sacred and profane, fully carries out this fact in its details of economical processes, &c. Unfortunately, the chemical analysis of vegetable colours is all but impossible in the condition that they have been kept from antiquity, and as now preserved in our museums, or probably the dyer of the present day might receive some valuable hints from his predecessors of old.

The discovery of America resulted in a great and invaluable accession to the list of dye-materials. In 1518, the Spaniards found out the native use of cochineal, in Mexico; and, not long afterwards, its use was introduced into Egypt. We are indebted to Mr. Barlow for the following account of the discovery of its uses in connection with a solution of tin, which, although apparently accidental, is simply another proof of what we have repeatedly observed—that no really valuable discovery, although based on accident, can be considered in its development as solely due to that cause; for we shall see that the person who made the discovery was actually engaged in researches tending towards that direction. Mr. Barlow remarks as follows :—

"The tincture of cochineal (that is, a solution in spirits of wine) alone yields a purple colour, not very pleasant, which may be made into a most beautiful scarlet by a solution of tin in *aqua-regia* [nitro-hydrochloric or nitro-muriatic acid, for which see p. 109, *ante*]. Mr. Rühlenkamp, of Bremen, one of the most learned dyers in Germany (1830), and who has studied with great care every improvement in the art, gives the following history of the modern scarlet dye :—The well-known Cornelius Drebbel, who was born at Alkmaar, and died in London in 1634, having placed in his window an extract of cochineal, made with boiling water, for the purpose of filling a thermometer, some *aqua regia* dropped from a phial, broken by an accident, which stood above it, and converted the purple dye into a most beautiful dark red. After some conjecture and experiment, he discovered that tin, which had been dissolved by the *aqua regia*, was the cause of the change. He communicated his observations to Küffelar, an ingenious dyer at Leyden, who was afterwards his son-in-law. The latter brought the discovery to perfection, and employed it some years alone in his dye-house, which gave rise to the name of Küffelar's colour. In the course of a little time the secret became known to one called Gülich, and also to another person of the name of Van der Vecht, through whom it became known to the celebrated Giles Gobelin, at Paris, who there erected a large dye-house. About the year 1643, a Fleming, named Kepler, established the first dye-house for scarlet in England, at the village of Bow, near London, on which account the colour was called, at first, 'Bow dye.'"

About twenty-five years after the introduction of cochineal colour as a dye into this country, Hooke, the celebrated and bitter opponent of Newton—the "Jack of all Trades" in experimental science, and master of none—if we may be so allowed to express our opinion of that man and his writings—discovered a method of printing simultaneously, yellow, blue, green, and purple colours on a piece of calico, that stood the action of hot soap and water; and which he exhibited at a meeting of the Royal Society, in November, 1669. Hooke had been, two years previously, requested to translate a work on dyeing, by that society. We may here mention a name that has long been identified with art-progress; and one of the family, the late Marquis of Lansdowne, has been by no means behind his ancestry in that respect. Sir William Petty, who founded the House of Lansdowne, was one of the first members of the Royal Society, to which he presented the model of a double-bottomed ship, designed to sail against wind and tide. He was a man of most varied accomplishments; studied at Leyden, Paris, and Oxford; was simultaneously professor of anatomy and music (the latter office being held in connection with Gresham College); secretary to Henry Cromwell, in Ireland; and author of numerous works on science, trade, mathematics, chemistry, political economy, &c., &c. But, for our purpose, we have chiefly to draw attention to the fact that he was author (*cir.* 1667) of the first work published in the English language on the art of dyeing. This was entitled *An Apparatus to the History of the Common Practice of Dyers.*

For a long time after this period the art of dyeing made little or no progress in this country. On the contrary, however, in France every attempt was made, consistent with the then condition of chemical science, to carry on the art to the highest degree of excellence; and it was placed under the special supervision of the government, by which its pursuit was carefully fostered by encouraging investigations, and assistive legislative enactments. In this country, towards the close of last century, the celebrated chemist, Dr. Henry, rendered essential service to its progress by original investigations, and by the publication of the results he arrived at. Living at Manchester—then, and ever since, the centre of the cotton, dyeing, bleaching, and printing trades—he availed himself of numerous details and facts to improve various processes. Amongst his productions in this respect, we may especially notice a Paper that he communicated to the Philosophical Society of Manchester,

entitled, *On the Nature of Wool, Silk, and Cotton, as objects of the Art of Dyeing; on the various Preparations and Mordants requisite for these different Substances; and on the Nature and Properties of Colouring Matter.* In this he propounded most important facts and views in respect to the chemical and practical pursuit of the art, and that of calico-printing, especially pointing out the value of the acetate of alumina, in place of common alum, as a mordant for calico-printing and dyeing, in regard to cotton. Also, towards the close of the last century, Dr. Bancroft rendered great service to the dyer by publishing a work that gave a *résumé* of the discoveries and applications made by continental chemists, such as Macquer, Dufay, Hellot, and Berthollet. He described the action of tartar, in combination with a tin solution, as productive of scarlet with cochineal. He also was the first to introduce the use of quercitron bark as a dye-stuff for producing yellows, then a discovery of considerable importance, but since tempered considerably in its value by more recent discoveries of material, and improved chemical processes.

Within our own time, Dr. Ure, Mr. Walter Crum, of Glasgow, and others whose names it would be invidious to select, have combinedly aided to bring the arts of dyeing and calico-printing to the perfection in which they now exist. But, as we have already stated, the greatest discovery and application of chemistry, in both of these arts, have been those in respect to aniline, or coal-tar colours, that bid fair, by their beauty, brilliancy, permanency, and ease of manipulation, to drive most other sources of dye-colour out of the field.

Having thus briefly pointed out how some portions of the art of dyeing have been gradually developed, we may now pass on to consider how, by various methods or processes, and by the use of materials, the peculiarities and properties of which have been already described in our preceding pages, the dyer is enabled to produce the results so pleasing to the eye, gratifying to the taste, and that foster refinement and art-progress generally. And here we may pay a humble tribute to the excellent effects that have arisen by the establishment of Schools of Design in many parts of this country, but especially in those districts in which the labours of the teachers employed therein are calculated to be most beneficial. But a few minutes before penning these lines, a friend has favoured us with a sight of copies of designs produced for calico-printers by him about forty years ago, when he exclusively devoted himself to that branch of art. It was highly remunerative; in but few hands; and, indeed, a monopoly. But now, taste has been so much improved, and artistic knowledge has been so much extended by the institutions to which we have just referred, that whilst still a "paying" pursuit, the quality and quantity of designs afforded far exceed those of the period to which we have referred, and reflect great credit on those who have been instrumental in bringing about such improvements, and thus improving the taste of both buyer and seller.

The preparation of liquors, or baths, depends on the soluble condition of the colouring matter, when derived from vegetable sources; and, as we have already found at p. 372, *et seq.*, these are very numerous.

Of late years, colouring matter, obtained from mineral substances, has been of great service in dyeing operations, evidencing that the principles of chemical science are gradually working their way into dye-house operations; and hence giving us hope that, eventually, the precision of science may sway such processes and operations.

Lastly, and of most present importance, is the use of coal-tar dyes, which promise to be productive of the most important result to the dyer; facilitating all, or nearly all, of his operations; making them almost of popular use; but yet expanding, to a great extent, the art-objects which the operation of dyeing is intended to effect.

Now, practically speaking, dyeing may be divided in its operations into two kinds or classes. 1st. That in which the colours derived from vegetable sources are used, together with certain mordants; with occasional use of mineral combinations, such as that of the prussiate of potash and a metallic salt, or chromate of potash and a salt of lead; and, 2ndly, the aniline system of dyeing, in which most of the difficulties of the former method are avoided or modified.

It will, therefore, be advisable that we should enter in detail into both of these methods; and although the first one is gradually being replaced by the second, its entire replacement must even yet be a work of time. Indeed, we are by no means sure that even the valuable discovery of the coal-tar dyes may not eventually be replaced, and at no remote date, by even simpler processes.

There are certain standard colours, of which others are chiefly modifications. In optical science such are called primary; and, according to the present opinion of philosophers on the subject, they are three in number—viz., red, yellow, and blue; but, formerly, it was thought that there were seven, as we have already explained at p. 86, *ante*.

In dyeing operations, many modifications of these colours, by their union or blending, are effected; and it would be difficult to name all the tints and shades thus afforded. They all result, however, from an imitation of the colours noticed in natural flowers. In respect to these we may quote the remarks of an eminent writer on Botany—Dr. E. Smith. He says—

"The colours presented by plants are exceedingly varied, and all alike depend upon the presence of colouring principles in the cells of colourless tissue.

"There are eight principal colours recognised in vegetables—viz., white, gray, brown, yellow, green, blue, red, and black; and each of these has many distinct shades.

"Of these shades of colour nine have been associated with *white*—pure, snow, ivory, chalk, and milk-white; with silvery, whitish, turning white, and whitened.

"A similar number is also attributed to *gray*,

and are designated ash, lead, slate, and pearl-gray; smoky, hoary, rather hoary, and mouse-coloured.

"Twelve have been computed in connection with *brown*—viz., brown, chesnut, deep, and bright brown; rusty, red brown, rufous, and cinnamon-coloured; with lurid, sooty, and liver-coloured.

"*Yellow* has twenty shades; thus—lemon, yellow, golden, pale, leather, waxy, and Isabella yellow; sulphur, straw, ochre, orange, apricot, and saffron-coloured; testaceous, tawny, and livid.

"There are seven varieties of *green*, of the shades of olive, grass, sea, yellowish, apple, meadow, and leek.

"*Red* has seventeen shades—carmine, rosy, purple, sanguine (or blood-coloured), scarlet, cumaba, vermilion, coppery, brick, flame-coloured, &c.

"*Blue* has but seven—viz., Prussian blue, indigo, lavender, violet, lilac, and sky-blue.

"*Black* has four—pure, coal, raven, and pitch-black.

"Thus as many as eighty-six different shades of colour have been determined to exist in plants."

Now, our means of imitating these, as derived from vegetable sources, are very numerous, as we have shown in the alphabetical list given at p. 97, *et seq.* They are imparted to textile substances either of their natural colour or modified by various mordants; hence some of them are capable, by the latter means, of giving several different colours. We may range all these, in their colour-giving powers, as follows, omitting, of course, the coal-tar dyes, which we shall deal with in their practical application separately:—

Black Dyes.—There is no substance that we are acquainted with from which we can practically obtain a black dye directly. In the cashew-nut order, or *Anacardiaceæ*, natives of hot climates, there are some species that yield a black. The marking-nuts, the fruit of an East Indian tree, the *Semecarpus anacardium*, contain a black corrosive juice, which is employed in India to mark cotton cloth, being improved for that purpose by the addition of lime and water. But, practically, it is useless in this country, on account of its great expense. Blacks of all kinds, therefore, are obtained by the action of tannin, or astringent matter, on an iron mordant. For this purpose, the bark of the alder, catechu, galls, gambir, kino, logwood, oak-bark, sumach, valonia, and, indeed, almost any plant-product that yields a soluble astringent can be used.

Gray Dyes.—These, although, philosophically, a modification of white, are, in the dye-house, dealt with as a modification of black dyes; hence, by using weaker baths and various mordants, together with one of iron, most required shades of gray may be obtained. Orchil, fustic, logwood, &c., with an iron mordant, afford various tints of gray.

Brown Dyes.—The various shades of brown may practically be considered as modifications of red, and therefore their vegetable sources are the same, but varied by the action of mordants. A mahogany colour is produced on cotton by the action of the yellow prussiate of potass on the copper contained in blue-stone, or sulphate of copper (see *ante*, p. 117). Aloes, catechu, madder, &c., afford brown with proper mordants.

Red Dyes.—The sources of these dyes are very numerous. For ordinary purposes, camwood, or barwood, Brazil, sappan and sanders-wood, are much used. Safflower yields very rich varieties of rose for dyeing silks. Madder, or rather its colouring principle, garancine, is of extensive use, especially for producing Turkey-red. Cochineal is also largely used in dyeing, with a mordant of tin. Lac is similarly employed; and from both scarlet and crimson may be obtained. Kermes, as we have already explained, has been entirely substituted by cochineal. Alder, arnotto, barberry-root, bed-straw, orchil, &c., also afford various shades of red; the latter if treated by an acid, for its natural colour as a vegetable production, and extracted by ammonia, is a blue.

Yellow and Orange Dyes have also very numerous sources; amongst which we may mention alder, arnotto, barberry-root, bedstraw, dyer's broom; the berries of several species of buckthorn, as the French, Persian, Spanish, Turkey, yellow, &c.; fustic, heather, kino, pomegranate-root, quercitron, saffron, sumach, turmeric, weld, wongshy, &c. The most permanent and brilliant of these dyes are derived from the action of bichromate of potash on a salt of lead for yellows, modified to an orange by lime or alkaline solution, as already explained at p. 113, *ante.*

Blue Dyes.—Practically indigo is the best source for blues. By the action of prussiate of potash on a persalt of iron, the Prussian blue is obtained. Woad has been replaced by indigo.

Violet and Lilac Dyes.—These may be obtained by regulating the strength of logwood liquor, in relation to an iron mordant, by which all shades of lilac, violet, slate, &c., may be obtained. The lichen dyes, as crottel, cudbear, orchil, &c., if alkaline, also afford varieties of these shades.

Green Dyes are mostly derived by uniting blue and yellow; indigo, and many vegetable yellows, being successively imparted to the fabric. If goods are first dyed by indigo, then passed through a solution of sugar (acetate) of lead, and finally through one of bichromate of potass, various shades of permanent green may be produced (see *ante*, p. 113). Arsenic and copper afford a rich green (see p. 115, *ante*).

Such is a synoptical view of some of the leading results obtained by the use of mineral, vegetable, and some animal matters, omitting the coal-tar series. The modes in which they are employed, or have been, must now be considered in their practical details. In so doing, we shall endeavour to avoid, as far as possible, all terms or modes of phraseology that might be of a too scientific nature for many of our readers; but on many of these we may be permitted to urge the fact, that precise names of compounds, expressing their constitution, are of great value;

and although, perhaps, difficult at first of comprehension to those unaccustomed to their use, eventually will save much time and trouble.

Blue Dyes—Indigo, and Prussian Blue.

We commence a relation of the practical details of the dye-house, as recommended by some of the best authorities, with a description of the various methods by which indigo is rendered susceptible of imparting several shades of blue; and also of the blue colours produced by the action of the yellow prussiate of potass on any salt containing a sesquioxide of iron.

It has been already stated, that indigo, as a natural product, does not afford directly a blue dye, but that, by various processes, its leaves are caused to afford this extremely valuable and permanent dye-colour. It may be safely said that there is no dye-stuff in present use that has so many peculiar properties especially adaptable in the art. As a rule, all vegetable blues turn red by the action of acids; and oxidating agents, such as the air, &c., all have a similar tendency. Light, animal secretions and excretions, &c., &c., all have, more or less, a destructive effect on most colours; but textile fabrics dyed by indigo generally withstand all these agencies; hence it is invaluable for the purposes to which it is applied.

We have previously pointed out that there are chiefly two methods that render indigo, as imported into this country, available for the purposes of the dyer. One consists in rendering the indigo soluble by dissolving it in strong sulphuric acid; and the other in deoxidating it; that is, in reducing the indigo to a soluble state by removing a certain quantity of the oxygen it had combined with, by changing it from the white to the blue condition. There are several opinions as to the exact scientific exposition of this question; but we shall not here enter into them, because they are really more theoretical than practical in their nature. Like the question of chlorine, and its synonyme, oxy-muriatic acid, that agitated philosophers in the days of Davy, whilst the practical result was the same, the theory greatly differed. But it matters not to the bleacher whether chlorine be a simple body (as most universally admitted), or whether it be a compound of muriatic (hydrochloric) acid and oxygen. So with the change that indigo passes through in its preparation for dyeing purposes; whilst the philosophical chemist may, and must, have his right to the expression of an opinion, the dyer may be safely excused from entering into such discussion.

Chemic, Saxon Blue, China Blue, and Extract of Indigo, are terms given synonymously to indigo dissolved in sulphuric acid. But mere solution does not occur in preparing indigo thus for the dyer's use; a real chemical compound is formed; and, in fact, a sulphate of indigo is produced. To explain what we here mean, it will be sufficient to say, that if a piece of zinc be placed in a little sulphuric acid and water, the metal will be gradually dissolved; and if the solution be evaporated, small white crystals, greatly resembling those of Epsom salts, will be obtained. Now, if we act on indigo by means of sulphuric acid, we produce a sulphate analogous to the salt found in the white crystals produced by this combination of zinc with sulphuric acid, and hence called *sulphate of zinc.* Thus, as the combination of the acid with the indigo, and, similarly, of it with the zinc, give rise to salts, they are both called sulphates.

This solution of indigo was first called Saxon blue, because its employment was first effected in Saxony, long the home of the wool trade. But ordinary oil of vitriol, or sulphuric acid, is rarely of sufficient strength to effect a proper solution of indigo. The best acid of commerce rarely exceeds, in specific gravity, that denominated by 1·845; that is, if a bottle held exactly 1,000 grains of distilled water, and this was filled with the acid we have named, it would then weigh 1,845 grains (see remarks on Specific Gravity, at p. 128, *ante*).

Another kind of acid is manufactured for this purpose. The ordinary kind is produced by passing the fumes of burning sulphur, of nitric acid, and steam together into large leaden chambers, when a peculiar series of changes take place, resulting in the formation of sulphuric acid, that is condensed by water contained at the bottom of the chamber. This acid is then concentrated, and, to free it from sulphate of lead, &c., is distilled in platinum stills, by which method the acid of 1·845 specific gravity is obtained. But that required to dissolve indigo is of higher specific gravity, reaching about 1·900; in reference to water = 1·000. It is obtained by distilling sulphate of iron or copperas, which consists of sulphuric acid, oxide of iron, and water. The latter is first driven off by heat, and the remaining copperas is then distilled, when the strong acid is thus produced. It is generally called Nordhausen acid, from the fact of its having been first produced at a commercial town of Prussian Saxony, noted for its extensive woollen factories, chemical, oil, and other works. Hence, also, the term Saxon blue; this product and the acid having both been identified in their early history with Saxony.

Two distinct products seem to arise from the union of indigo with sulphuric acid—namely, the sulpho-indylic and sulpho-purpuric acid. The first results from a complete solution of the indigo, which can only be effected by using the strongest acid just described. It is considered to be composed of one equivalent of indigo, and two of sulphuric acid; and thus it forms what we should call in chemistry a bisulphate of indigo, the addition of the syllable *bi* indicating the double proportion of acid; it has a fine blue colour. The other is a composition supposed to consist of one equivalent each of acid and indigo, and it has a purple colour. If it be diluted with water a portion of the indigo is thrown down; hence it would appear that the water has either a stronger affinity for the acid than has the indigo; or what is, perhaps, more likely, the water forms what we call in chemistry a hydrate of indigo. Thus, if ammonia be added to a solution of alum, a white precipitate is

thrown down, which consists of an oxide of aluminium (see *ante*, p. 111) and water.

Several precautions are required in preparing the Saxon blue for dyeing purposes. In the first place, the strong Nordhausen, or fuming sulphuric acid, has an enormous attraction for water. Indeed, the ordinary acid manifests this to a great degree; for if added, in its concentrated state, to water, the temperature of the liquid is instantly raised sufficient to break almost any glass vessel in which the mixture is effected; it converts syrup into a black charcoal mass by abstracting its water, and generally chars all organic substances. If, then, in making Saxon blue with the strongest acid, atmospheric air have free access to the vessel, the acid will become diluted; and instead of the solution of indigo, or sulpho-indylic acid being formed, much of the other compound will be generated. The reason that the strong acid fumes is, that it unites with the moisture in the atmosphere, just as muriatic (hydrochloric) acid, or spirits of salts, does when a stopper is taken out of the bottle holding it.

Other precautions are also requisite; and one is that of allowing sufficient time for the acid to act on the indigo, and not to hasten the process. Similar advice has been already given in respect to the production of tin "spirits," at p. 115, *ante*. If it was not for the absorbent powers that the acid has for water, perhaps the best plan of producing the Saxon blue would be to put a little of the indigo into a mortar, and gradually add the acid, working the two together with the pestle meanwhile. But this plan is inadmissible, for the reasons just stated. The indigo itself also contains water, and absorbs it. Possibly, therefore, it would be desirable to dry it.

In respect to the preparation of Saxon blue, the following directions, by an able practical man, are valuable, although we recommend about one-fourth more acid than he advises. Bergman recommends eight parts, and Dumas fifteen parts, of the strongest acid to one of indigo. The directions we just referred to are as follow:—The indigo is to be reduced to an impalpable (extremely fine) powder, either by grinding it in a mortar or a mill; and completely dried by placing it upon a sand-bath or flue for some hours, at a temperature of about 140° or 150°. For each pound of indigo, ten pounds of highly concentrated sulphuric acid are put into a large jar, or earthen pot, furnished with a cover. This is kept in as dry a part (place) as possible, and the indigo is added gradually in small quantities. The vessel is to be kept closely covered, and care taken that the heat of the solution does not exceed 212°. When the indigo is all added, the vessel is to be placed in such a situation that the heat may be kept at about 150°; and it is to be allowed to stand, with stirring occasionally, for forty-eight hours. These precautions being attended to, we have uniformly found that any failure occurring was clearly traceable to impurities of the indigo, or the weakness of acid used.

It will be noticed that the chief precautions requisite to procure the best and most effective solution of the acid are—*first*, to obtain as pure an indigo as possible. Now, as we have already remarked at p. 100, *ante*, and for reasons there stated, we can propose no plan by which an accurate judgment can be given as to the value of any sample of indigo before purchase: this can only be properly found in its use, except by those whose lengthened experience affords them aid. *Secondly*, it is necessary that the acid should be as strong as possible; and, for this purpose, the specific gravity of any sample should be taken, before purchased, by methods already given at p. 129, *ante*. We must here notice that the ordinary sulphuric acid often contains sulphate of lead, which raises its apparent gravity to a fictitious value. This is easily discovered by diluting it with water, when, if any of the lead salt be present, a white precipitate will gradually be thrown down. Another precaution that should be observed is, that the sulphuric acid contains no nitric acid or its compounds—a by no means uncommon occurrence—and that would infallibly cause the indigo solution to be seriously impaired. This may be detected by the smell. Hydrochloric acid might possibly be present; but this is of comparatively rare occurrence. *Thirdly*, in the list of precautions, care must be taken to dry the indigo, and prevent access of atmospheric air to the acid before or whilst the solution is being effected. We should, therefore, recommend the use of a flask with a narrow neck, in place of a jar, to effect the mixture; for, of course, the wider the top of the vessel the more air will enter, and more fully will the acid become diluted. *Lastly*, it is desirable that, whilst the solution does not attain too great a heat, it, at the same time, should be kept up at a moderate temperature. Hence the necessity of using the thermometer, as already recommended at p. 128, *ante*, and which, it will be seen, must be of essential importance in the preparation of the blue. The great causes of failure in preparing chemic, are acid of deficient strength, and impurity of the indigo.

A simple test for the safe progress of this process is that of putting a few drops of the solution, now and then, on a glass plate. If a greenish colour is observable, the process has not gone sufficiently far, or the acid is too weak. The test of exact success is the production of a fine blue colour, which shows that the indigo has attained that condition most of value, and, therefore, of economy for the purpose of the dyer.

The single sulphate—that produced by too weak an acid, and comparatively insoluble in ordinary water—if formed during the process of solution, is soluble in alkaline solutions, and affords a blue colour; but, for dyeing purposes, it is, in respect to the trouble and cost, of less value to the dyer than the preceding.

In using this solution for dyeing purposes, various proportions of it to water have been recommended. Woollen goods rapidly absorb the colour; so much so, indeed, that a piece of woollen cloth may be made a kind of repository

for it; because, if boiled in a bath of one part of the indigo solution, to, say twenty or thirty of water, the cloth will absorb the colour. When light blues are required, some of this dyed cloth may be put through hot water, when a portion of the colour is thereby extracted, and forms a bath, from which some goods may be dyed. The addition of a small quantity of carbonate of potash facilitates the extraction of the blue from the woollen cloth, and so strengthens the dyeing powers of the bath. In dyeing cotton goods, it is requisite to neutralise the free acid, which is done by adding chalk in fine powder. This must be carefully effected, especially when greens are to be dyed, by dipping an already dyed article, of a yellow colour, into the liquor. The presence of free acid is readily determined by dipping a piece of white blotting-paper, previously turned blue by orchil, repeatedly into the bath. So long as any acid is present the paper will be turned red; but the moment that the chalk has neutralised it, then, of course, no free acid being present, the paper will retain its blue colour. As the chalk is added to the liquor the bath should be constantly stirred, so that the neutralising action may, in all parts, be simultaneously carried on. This point is of considerable importance; for neglect of such a precaution would inevitably cause a loss of material.

We do not feel it advisable to give definite instructions for the exact proportions required either for dyeing greens or blues, in reference to the sulphate of indigo. As we have already remarked, this substance affords a rare instance, in vegetable dye-stuffs, of the non-necessity of a mordant. The indigo is, consequently, readily attracted to the fibres of all textile fabrics, and proper care alone is required to regulate the intensity of the colour by regard to the quantity of material. When, however, a mordant is required, as in reds, &c., much depends on the action of this on the bath, as to the amount of colour communicated to the fabric; for if a large amount of mordant be upon it, of course an equally but comparatively large quantity of dye colouring matter will be precipitated. Thus it is that we are enabled to produce from logwood, by an iron mordant, so many shades, running from a violet to a deep blue-black.

A great advantage arising in the mode of employing indigo in solution is, that a bath is readily prepared for dyeing purposes. The method we shall presently explain of forming the blue vat is, perhaps, less expensive, but more troublesome.

There is one point to which we have not alluded, and that is, the temperature of the bath used for dyeing blue by means of the Saxon blue, or chemic. It is generally recommended to add boiling water, in whatever proportion desired, to the solution of indigo in a wooden tub or vat. But when employed on the large scale, steam from a boiler may be used to heat the water, before or after the Saxon blue, or chemic, is added. For this purpose, as free sulphuric acid is present, it is desirable that a lead pipe be used to send the steam into the water, because one of iron would be rapidly acted on, and produce copperas or sulphate of iron, which might act prejudicially; because, if so produced, it would, especially on cotton goods, attach itself, and, unless carefully washed away afterwards, might produce a reddish tint, or, at all events, otherwise injure the beauty of the blue.

It is also desirable that water free from lime, &c.—that is, as soft as possible—be employed,—another instance of the value of the instruction we gave at an early part of this work, in reference to the purity of water employed in dyeing operations generally. In fact, throughout our investigations into the nature and practice of dyeing operations, we shall constantly perceive how essential this matter is to success in the production of brilliant and permanent colours.

Another method to which we may refer is the necessity of abundant washing in water, especially of cotton goods, if any free acid be allowed in the vat in which they have been dyed. If this be not attended to as they are dried, and the water evaporates, the acid is left on the surface of the yarn or fabric in a concentrated state. It will instantly act thereon, and almost certainly destroy the texture. We have frequently noticed this result in cotton yarns that have been dyed in vats containing even weak acid solutions; and, therefore, earnestly call the attention of the practical man to this important matter.

It is, of course, necessary, in every case, that cotton, wool, and silk should be carefully freed from all resinous, oily, or gummy matter before dyeing. Instructions have already been given generally on this subject. Speaking of cotton goods that are to be dyed of a light blue, it is desirable that they should be wholly or partly bleached, especially in respect to yarns. Calicoes are generally, with all other woven goods, dyed blue by means of the blue vat, that we shall next describe. If the yarn is not supplied to the dyer in the bleached state, it is desirable that he should, in many cases for his own credit, remove a portion of the usual natural yellow tint. In a further part of this work full instructions will be given in respect to the usual mode of bleaching completely, as usually carried on. Suffice it to say, for the present, that if the yarn be first boiled in a moderately strong solution of soda, to remove grease and resin, then dipped in a weak solution of chloride of lime or bleaching powder, and left therein for two or three hours; next left to drain on a hurdle, and afterwards dipped into water containing as much sulphuric acid as will make it as sour in taste as lemon-juice, it will be sufficiently bleached for such a purpose. It must be abundantly washed in water, to remove all traces of chlorine and acid, and may then be transferred, without drying, to the blue liquor, or chemic.

The preceding method of dyeing by indigo is not followed generally for piece goods. The blue vat is prepared for that purpose, and the process differs from that just described in many important particulars.

At p. 99, *ante*, we have given a brief outline of the chemical principles on which the blue vat

is prepared. The indigo, as imported, is insoluble in any menstruum except the strongest sulphuric acid, the use of which we have already described in connection with the preparation of Saxon blue. According to the usually received theory, blue indigo is an oxide of white indigo; but it has been suggested that, on the contrary, the blue indigo is the result of the white combining with hydrogen. It does not matter, in practice, which theoretical view we take; personally, we prefer the theory of oxidation, by which we will suppose that white indigo becomes blue by absorbing an equivalent of oxygen; or, in other words, that the blue variety is an oxide of the white.

In preparing the blue vat, advantage is taken of the great attraction which a protosalt of iron has for oxygen, and also of the alkaline nature of lime. In respect to the constitution of a protosalt of iron, we may refer our readers to the remarks on this subject, already given at p. 112, *ante*. Now, if copperas, which naturally has a green colour in the form of crystals, be exposed to the air, it gradually becomes covered with a red rust-like powder, which is caused by the protoxide of iron it contains being converted into the sesquioxide. The protosulphate of iron is composed of sulphuric acid united to the oxide of iron, which consists of one equivalent each of metal and oxygen; whereas the sesquioxide, which is the base of the persalts of iron, has a composition of two equivalents or parts of metal united with three of oxygen; in other words, it contains one-half more oxygen than the protoxide, weight for weight.

The lime which is used in the preparation of the blue vat answers a double purpose. In the first place it precipitates the sulphuric acid, in combination with the oxide of iron in the copperas, the sulphate of lime being formed. This being insoluble, or nearly so, in water, sinks to the bottom of the vat. But another portion of the lime unites with the indigo, and dissolves it. Hence the necessity of the lime to form the dye-liquor.

The proportion in which the materials are used necessarily must vary; for it will depend on the quality of each. It is, as a rule, recommended, that one of powdered indigo, two of copperas, and from two and a-half to three parts of lime—all by weight—should be employed. The lime can at all times be obtained sufficiently pure and good for the purpose. Not so the indigo and copperas. In respect to the indigo, the buyer must use his own judgment; for, as we have previously stated, there is no practical method of judging certainly of its quality by testing a sample taken as a reliable specimen from the bulk.

In regard to the copperas, many opinions have been expressed respecting its variety in quality. Several years ago we noticed this fact whilst using large quantities of the salt in dyeing raw cotton black with it and logwood. The sulphate was purchased from one of the most respectable drysalters in London, in large bulk, but at a fair price; and although it was not important that the black should be of anything like first quality as a dye, still the various depths of colour obtained with the same logwood, but successive and fresh supplies of the copperas, were puzzling, and sometimes annoying. At times we blamed the workmen for carelessness; but on finding that, by personal superintendence, we arrived at no better results, we were obliged to lay the fault to the iron salt.

We regret not to have made experiments on the subject; but have much pleasure in giving the result of an able practical chemist and dyer, who, like ourselves, has found the "fix" that the practical man may occasionally get into. He says—"It may still be inquired, what constitutes the difference of these varieties of sulphates of iron alluded to? We are sorry to say that we cannot give a decided answer to this inquiry, but will merely mention the results of our own experience relative to the question. Our first method for ascertaining the real value of copperas, was by taking a weighed quantity (generally twenty grains) of the salt; dissolving it in distilled water; boiling the solution, with the addition of a few drops of pure nitric acid, to peroxidise the iron, which was precipitated by adding an excess of ammonia [see *ante*, p. 112]. The precipitate was placed upon a filter, thoroughly washed and dried. The peroxide of iron was then carefully weighed and noted. The average results of these trials were as 21 to 24; that is, 21 pounds of good old copperas (or what has been crystallised for a considerable time), as dyers term it, was equal to 24 pounds of new copperas. These results corresponded with the practical effects experienced in working the vats; but mere extra quantity of copperas, necessary to keep the vats in working condition, when the bad stuff is used, is not the worst (evil). It is also necessary, under these circumstances, to add an extra quantity of lime, which, in technical language, causes the vats to swim; that is, the precipitate swims, and is long in settling to the bottom; the goods come in contact with it, and the colour is deadened. Under this emergency the dyer uses a little carbonate of soda, or potash, which forms soluble salts, and causes no extra precipitation. In order to ascertain the true amount of this evil by direct experiment, the writer took a solution of nitrate of baryta, in the common alkalimeter, at such a strength that one graduation of the alkalimeter exactly precipitated the acid of one grain of the best copperas. The average difference found by this method of experimenting was as 20 to 21; and experience taught, that for every fifteen pounds of bad copperas, two pounds extra of lime had to be added. It was probably the result of such experience which led dyers to suppose that there was a bisulphate of the protoxide of iron, and to give instructions how to guard against it. As this watery-looking, whitish, blue-green copperas is crystallised from an acid solution, it is probable that the extra proportion of acid which is found in it, is owing to a portion of the mother liquid being mechanically combined with the crystals, but not forming an essential ingredient in the composition of the salt."

With this latter view we fully coincide, not on account of any experiments that we made, but from a result which the preceding quotation calls to mind. Our copperas was always kept in bags made from the wrappers of old cotton bales, each containing exactly a hundredweight, so that the quantity used by the dyer might be under constant control. Sometimes these bags would become completely rotten. This could not arise from any action of the copperas; because, if commercially pure, it is a neutral salt. We therefore came to the conclusion, on this ground, that frequently the crystals had an extra quantity of acid mechanically attached to them. Another fact that we also noticed was, that such crystals were always wet. This would naturally arise from the attraction that the uncombined sulphuric acid on them had for atmospheric moisture.

The same writer has made some judicious observations respecting various impurities to which copperas is subject, which we shall take the liberty of quoting for the use of our practical readers:—"A very common impurity in sulphate of iron is sulphate of alumina. The deleterious nature of this salt does not consist in its action upon the indigo, but it introduces to the vat a good portion of sulphuric acid; and, as it forms a double salt with the sulphate of iron—which double salt combines with twenty-four equivalents of water—its presence may account for the various results obtained * * * * with bad copperas, and its evil effects in the vat. It is, no doubt, the presence of sulphate of alumina that renders Scotch copperas so much inferior to the English.* The presence of alumina may be detected by its giving the peroxide of iron, when precipitated, as already described, by ammonia, and filtered, a very bulky and clayey appearance. If this precipitate be dissolved in muriatic (hydrochloric) acid (or, technically, "spirits of salt"), and the iron again precipitated by caustic potash, added in excess, and filtered, the alumina now in solution passes through the filter, and may again be precipitated by adding ammonia. It is a bulky white precipitate. The presence of sulphate of zinc and copper may be detected by a similar process—the iron being peroxidised and precipitated by ammonia. If copper be present the supernatant (top) liquid has a blue colour. It may also be detected by putting a piece of clean iron in the copperas (solution). The copper is deposited in the metallic state on the iron.† If zinc be present, and a stream of sulphuretted hydrogen gas be passed through the clear filtered liquid, a white precipitate is obtained. This latter substance is very seldom present in copperas. The deleterious effects of these two substances are of the same nature: they hold their oxygen by a comparatively feeble attraction; so that, when any deoxidising substance comes in contact with them, they yield their oxygen to it, consequently their presence in the blue vat neutralises the effects of the sulphate of iron."‡

These judicious and really scientific remarks cannot but be of advantage to many of our readers; and we trust that they may result in preventing as well as affording a remedy for the evils to which we have drawn attention.

So far for the preparation of the blue vat. It must be remembered that goods immersed in it at first gain no blue colour. Yarns are dipped and well moved about in the liquor, wrung out, and exposed to the atmosphere. Piece goods may be advantageously passed through such a vat as we have illustrated at p. 126, Fig. 88, *ante*. The arrangement of the rollers allows a continuity of the operation on one or any number of pieces tacked end to end; and, by such a plan, much time and trouble is saved. Heat is easily supplied by steam issuing from a *leaden* pipe, and not one of iron, the reason of which we have already pointed out at p. 138, when directing as to the mode of heating Saxon blue, or chemic liquor. For yarn dyeing round tubs answer very well; and near each should be a wringing-post (see *ante*, p. 126), because each time the yarn is taken out it is desirable to remove, as much as possible, all superfluous liquor, not only to prevent waste, but also to leave no indigo solution merely superficially and not interstitially, or in the pores of the yarn.

The depth of colour obtainable from the blue vat depends partly on its strength and temperature, but especially on the number of times that the goods are dipped into it, and exposed to the air. These questions must, therefore, be left to the judgment of the dyer, who will easily be able to regulate his operations to obtain any desired shade that indigo is capable of affording. Of course, abundant washing is necessary, before the yarn or goods are dried, to remove acid, &c., &c.

Prussian Blue.—This mode of producing a blue colour on goods has the disadvantage of not being permanent in its results, and is, therefore, much below indigo in ultimate value, although cheaper in the first instance. The nature of the colour imparted varies, in some respects, from that afforded by indigo; for it has not that rich pure blue that is produced by the vegetable dye-stuff. As we have already pointed out, the colours resulting by the union of the prussiate of potash, either with an iron or other metallic mordant, are at once affected by alkaline solutions, as leys of potass, soda, lime, soap, &c.; converting them first to a dirty green, and, subsequently, destroying them altogether.

We have already pointed out and described, at p. 117, *ante*, the chemical constitution, manufacture, &c., of yellow and red prussiates of potash, and the modes of their employment with a salt of iron in dyeing Prussian blue. We there noticed the fact, that cyanogen and iron are the active

* In Scotland, much copperas is produced simultaneously with alum. The shale from which both are obtained contains iron united with sulphur as the sulphide, and, from this, copperas is prepared by the oxidating effects of air and moisture. (See our remarks on iron in alum, at p. 111, *ante*).

† See our observations on the adulteration of sulphate of copper with sulphate of iron, at p. 113, *ante*.

‡ See remarks on the effects of organic impurity in water, in respect to their deoxidising powers, that are given in the left-hand column, p. 94, *ante*.

agents in making the fine blue that is sold as a pigment, by the name of Prussian blue, and produced as a dye on cotton and woollen goods.

The usual method of obtaining this colour is to prepare what is called a prussiate tub. This consists of a solution of the yellow prussiate of potass—the ferrocyanide of potassium of the chemist—in water containing as much sulphuric acid, or oil of vitriol, as is sufficient to render the liquid about as sour as lemon-juice. It must be borne in mind that this acid decomposes the prussiate salt, and causes the evolution of hydrocyanic or prussic acid, which is not only dangerous to the workman, but is also a cause of loss of material, that should, as far as possible, be avoided.

The persalt of iron to be employed may be either the nitrate, or one afforded by boiling copperas, the sulphate of iron, with nitric acid, by which a persalt is produced. We have already spoken of this, and also of the use of chlorate of potass and a little sulphuric acid as oxidating agents, at p. 113, *ante*.

The method of producing the Prussian blue, of various shades, is very simple. The yarns, or goods, are first passed through the iron solution, wrung out, and then washed with water, or dipped into a weak alkaline solution, by which the iron salt is decomposed. On being introduced into the prussiate tub, a blue is at once produced, the depth of which will depend materially on the strength of the solutions of either salt employed. This plan is of comparatively limited use for cotton yarns; but piece goods are commonly dyed of a kind of ground-blue by this process. They are wrought first in the iron solution—preferably the nitrate—for about a quarter of an hour; then washed in water, and transferred to the prussiate tub. Thus the iron attaches itself readily to the cloth in the manner of a mordant, and the ferrocyanogen being liberated, affords the blue colour.

It may not be known to many of our readers that Prussian blue is readily soluble in oxalic acid. In this condition it has been largely prepared to make blue ink. We are not aware as to whether it has been used to produce colours on yarns or fabrics in this soluble state. It is more than probable that it would be too expensive; although, in certain respects, it might have some advantages. We have, however, no practical acquaintance with the results that might be obtained, and therefore merely mention it suggestively to our readers.

About the commencement of this century, the French government granted to M. Raymond 8,000 francs, as a reward for his discovering a method of dyeing silk by means of prussiate of potass and an iron salt. Mr. Barlow describes the plan thus:—He first converted, by gentle calcination, the green sulphate into a red sulphate, which he dissolved in sixteen times its weight of water, and filtered. The silk—prepared as for indigo dye, by removing the gum on its surface by hot water—was put into the solution of iron, and left there more or less time, according to the shade of blue wanted; it was then to be taken out, and wrung on a pole placed above the vat; afterwards it was thoroughly cleansed by being twice bathed, plunging and agitating each time in running water.

One ounce of the "ferroprussiate" of potash was dissolved in water at 167° for every twelve ounces of silk to be dyed; and on the prussiate being dissolved, one part, or even more, of muriatic (hydrochloric) acid was added, with a constant stirring. On the liquor acquiring a greenish colour, the silk was plunged into it, and stirred about until it had received sufficient colour; it was subsequently bathed and washed, to free it from any of the dye not intimately combined with the fibres.

The process was completed by stirring the silk about in water to which two pounds of spirits of ammonia had been added for each 100 pounds of silk that had been dyed; by which a much deeper and richer shade of blue was produced than by drying it without this last operation. It was stated, also, that the permanency of the colour was much more certainly ensured.

M. Raymond had evidently hit on the science of the whole process, from the fact of his first peroxidising the iron, and also in adding a proportion of acid to the solution of the prussiate. His final treatment with ammonia was judicious, because any excess could do no harm, as would either potash or soda; for the latter are fixed, whilst ammonia is volatile.

We have thus given an outline of the two leading methods of dyeing yarn and goods various shades of blue, derivable from indigo, and prussiate of potass with iron. Some of the blues thus afforded become grounds that are afterwards convertible into greens by means of yellow dyes; as, for example, quercitron, fustic, and other baths derivable from vegetable sources, or from a mineral yellow afforded by the action of the bichromate of potass on the sugar or acetate of lead—already noticed, and which will afterwards be more particularly described in its mode of use in the dye-house. The blues produced by aniline colours will also be described separately, under the head of Aniline Dyes.

Yellow Dyes—Mineral and Vegetable.

The vegetable world affords, perhaps, a greater variety of dye-stuffs that produce yellow and brown colouring matter, than of any other kind; and, possibly, some very interesting scientific principles may be involved in this fact that we have yet to become acquainted with. In the production of sources of blue, nature, indeed, has been niggardly in respect to plants; for, at the present day, we are practically confined to the use of but one—indigo—the properties of which we have just described *in extenso*, and that has entirely superseded the woad of our ancestors. Red colouring matter, again, is much more abundant than the blue; as, for example, that obtained from Brazil and other woods, safflower, cochineal, lac, &c., &c.

Generally speaking, the yellows produced in the dye-house from vegetable sources are very fugitive, despite the careful use of proper mordants. Those that have been most in use have

been fustic, quercitron, weld, various yellow berries of the buckthorn species, &c., &c. As a rule, however, dyes of a mineral nature, besides those of the aniline, or rather allied series (picric acid), have been substituted for vegetable colouring matter; less trouble being required, and the results obtained being by far more brilliant and permanent.

Quercitron bark was first brought into use in 1784, by Dr. Bancroft. His process was that of using a tin mordant with a bath of the bark, adding, for a brilliant yellow, about half as much alum as there would be of bark used, the latter being in the ratio of one pound to every ten of goods. The colouring principle of quercitron is called *quercitrine;* and it contains also a considerable quantity of tannin, which may be rendered useful, with an iron mordant, in producing an olive. As a basis for green, quercitron can be used with the acetate of alumina as a mordant. It must be borne in mind that the temperature at which this colouring matter is extracted is a point of importance. At a heat of the water extracting it not exceeding 90°, the richest yellow colouring matter is obtained; but when the water is raised to nearly a boiling temperature the tannin is dissolved out, and such a bath is more fitted to produce a brown. A brown may be produced with the bark by first dyeing the goods of a yellow colour, using the acetate of alumina as a mordant. A bath is then prepared, of one part of logwood to two of Brazil-wood, through which the goods are worked for a quarter of an hour. Alum is then added to raise the colour, after which they must be washed and dried.

Before the discovery of quercitron, fustic was largely used to produce yellows, and had been long adopted for that purpose. Indeed, in old dyeing books it was considered as the staple dye-material for these colours. It is now rarely, if ever, used for that purpose in dyeing cotton yellow, being chiefly employed for wool and silks, especially as a basis for green—a colour to afford which it may be, however, used for cotton yarn. A blue is first produced in the blue vat, and then mordanted with the acetate of alumina. A hot bath of fustic is then prepared, through which the yarns, &c., are passed. Like quercitron, good browns are producible with fustic baths, together with logwood and sumach; a little copperas is used, and afterwards the goods passed through a weak bath of logwood and Brazil-wood; the colour is raised with alum, washing and drying concluding the process.

Weld has similar uses to both the preceding, an aluminous mordant being employed. In its use, as well as in most other vegetable sources of yellow colours, great diversity of opinion and practice occur in respect to quantities of materials used; so much so, indeed, that we cannot safely recommend any particular recipe. This, however, is not so important as to be a matter of much regret, considering that the use of most of these dye-stuffs is gradually giving way to such as are of a mineral character. Again, with ordinary precaution, and proper use of mordants, no difficulty can be experienced in obtaining yellows from them, to the extent of which they are capable of affording those colours.

Chrome-yellows and oranges have already been alluded to at p. 113, *ante;* and they are now extensively employed in place of the preceding and other vegetable yellow-producing stuffs. We there explained the chemical characters of the two substances chiefly used—bichromate of potass, and the acetate or nitrate of lead. It may be interesting to some of our readers if we state, that a solution of the bichromate of potass communicates to paper certain photographic properties. For example, a solution of the salt is made in distilled water, and poured into any convenient but wide receptacle—as, for instance, a plate or dish. A piece of ordinary white paper is then to be floated on one side of its surface, so that it may be completely wetted by the solution, and at the same time be free from air-bubbles on its surface, which would leave a white mark. If such paper be dried in the dark, and placed with some object to be copied in a photographic printing-frame, or with a piece of plate-glass on both, so as to keep them together, and they are exposed to the action of the sun's rays, the light will convert such portions as have been exposed to its action to a brown colour; whilst those parts that have not been so acted on by light will remain of a yellow colour, that may be removed by soaking in hot water, which leaves the affected parts unchanged. This simple result has given rise to a branch of photography called the *chromotype*, of which there are some varieties that we need not here notice, because our chief reason for naming these results is, to indicate to the practical dyer the fact, that light has an immediate and strong action on a solution of bichromate of potass, imparted to vegetable and other substances.

Referring for any necessary information as to the manufacture of the chromate and bichromate of potash, the nitrate and acetate, or sugar, of lead, respectively, to pp. 113 and 114, *ante*, we may now enter into the details of the processes adopted in producing various shades, from light lemon to orange, by the use of these materials.

In using mineral dyes, it is desirable, as far as possible, from motives of economy, to employ what we term in science their mutual equivalents; that is, such quantities as represent the proportion in which they naturally combine to produce definite compounds. We have previously remarked that this is absolutely impossible in respect to vegetable colours; first, because we know very little of their chemical nature; secondly, for that we cannot make any proper analysis of their constitution; and lastly, because the sources from which we procure them vary so greatly, both in chemical and commercial value. Not so with mineral bodies, for these we can exactly analyse; we know they combine in definite and invariable proportions; and so we can, with great accuracy, state their proportions.

But when we apply such principles to the art of dyeing, we must not forget that we have an

element of difficulty to contend with. Thus, in using the bichromate of potash and acetate of lead as dyeing agents, we find that cotton, wool, and silk have varying powers of attaching such agents to their fibres; and, moreover, different qualities of each equally vary. Thus, a Surat or Madras cotton takes a yellow dye from such sources very differently to what American cotton would do; and if we alter the external character of each—say by bleaching—we gather another element requiring consideration. So that, despite of all our chemical knowledge, we must, as practical chemists, admit, on entering the dye-house, to profess the instruction of our practical friend, that we have by no means a straight course to pursue. Some of our obstacles we have already noticed at p. 131, *ante*.

Respecting these difficulties we quote some able remarks by one who has united a practical and scientific knowledge in his observations and teachings. Nearly in his words, the advice and instruction to the practical dyer, in respect to the materials we are now dealing with, are as follows:—

The proportions of the two salts vary according to the particular hue and depth of colour wanted; and, for deep shades, the goods are passed several times through lead (the acetate or nitrate, or both) and chrome (the bichromate of potass). The proportions used in the dye-house are—for dyeing a lemon colour, 10 lbs. of cotton; 4 or 5 oz. of the nitrate, with 12 oz. of sugar (acetate) of lead; and 6 oz. of the bichromate (of potash). If the shade is to be a little darker, 5 oz. of the nitrate, 11 oz. of the acetate, or sugar, of lead, and 6½ oz. of the bichromate of potass are employed: a very red shade of yellow requires 8 oz. of the nitrate; and an equal quantity of the acetate of lead, with 14 oz. of chrome (bichromate of potash), are needed. When dark ambers are wanted, the proportion of nitrate to the acetate of lead is increased; but the last is the highest proportion of bichromate to the quantity of lead (salts); and we need hardly say that it is just so much wasted. The proper proportions for dyeing yellow, even were the salts of lead entirely absorbed by the goods, is, as near as possible, one-half bichromate of potash to the lead salts, whether the nitrate or acetate be used. All above that is direct loss; and, as the salt of lead is never all taken up by the cotton, the proportion of chrome may be less than half of the lead salts used. However, it may be said that practice has dictated these quantities; and *the results of practice are more to be relied on than theory. Whether, then, is the theory or the practice in this case at fault?* [the italics are our own]. It will be observed that the depth of redness of the shade is in proportion to the amount of nitrate of lead used, and that it is the oxide of lead in the acid which gives the dye with the chromic acid of the bichromate of potash. Now, every 100 oz. of nitrate of lead contain about 67½ oz. of oxide of lead; and every 100 oz. of acetate of lead contain about 68½ of oxide of lead; hence the same weight of acetate of lead should give a richer dye, and take up, in proportion, a little more bichromate of potash than the nitrate; so that the practice of giving more bichromate of potash with the nitrate of lead is an error. It appears that the extra quantity is given for the purpose of reddening the hue of the yellow. How this is effected will be seen presently. When a piece of cloth is put into the nitrate or acetate of lead, it is merely soaked with (a solution of) the salt; there is no fixing of the oxide upon it; and if (afterwards it be) put through water, it (the lead salt) would be completely washed off. In this state, therefore, the (lead) salt cannot form a dye; it must be rendered insoluble. This is effected, as we have observed before, by immediate transposition from the salt of lead (of the oxide) to the bichromate of potash (that is, the chromic acid of the latter), when there is formed the insoluble chromate of lead. That portion of the salt which exists within the hollow fibres of the cotton becomes fixed; but all that is upon the goods, external to the fibres, is loose, and either falls off in the chrome-tub, or is washed off afterwards. This portion probably constitutes one-half, creating so much loss; and it is well known, that where chrome-yellow dyes are produced to a great extent, the chromate of lead thus formed is collected, amounting, in a short time, to hundredweights, and sold at a trifle to painters. But there is another evil attending this method. Say 100 lbs. of yarns are to be dyed a red shade of yellow; this will take 160 oz. of the salt of lead, which will contain 53 oz. of acid, and 107 of oxide of lead. If we suppose that all the lead salt is taken up by the goods—which is seldom (we should say *never*) the case—the 160 oz. should take only 73 oz. of bichromate of potash, although, in practice, they take 140 of bichromate; * * * leaving 67 oz. of bichromate of potash to be acted upon by the free acid, for the purpose of giving a red shade.

These remarks illustrate the difficulty we have already stated in reference to the question of quantity to be recommended whenever mineral dye-stuffs are employed. We shall, therefore, be justly excused, on the part of our readers, from dogmatising on the subject, still less from giving exact instructions in reference to the proper ratio between the amount of each salt to be used, and the weight of goods that may be dyed from solutions of such quantities.

Certain precautions that may be observed will, however, tend to diminish much of the loss that is caused by the circumstances we have previously stated. Of course, both the nitrate and acetate of lead are soluble in water to a considerable extent; but there are many methods of removing the acids with which they are combined, and of so rendering the oxide of lead insoluble; or, more correctly, of setting free a hydrate or carbonate of that oxide, both of which are insoluble under ordinary conditions, and in any case, but to a small extent, in water. Thus, if we add a solution of either the caustic or carbonated alkalies to one either of the nitrate or acetate of lead, decomposition at once ensues; each alkali seizes the acid with which the lead had been previously combined, and the hydrated

oxide (the oxide combined with water), or the carbonate (equivalent to "white lead"), is set free. A feasible method is thus, therefore, suggested of removing all superfluous lead solution, and in preventing waste of the bichromate of potass. It is that of immersing the yarns or goods in the usual manner in the lead solution; careful wringing, and subsequent immersion in a weak solution of either potash or soda. The hydrated oxide is thus precipitated on and in the fibres of the goods, and they are then ready for passing through the bichromate liquor or solution.

Partially, a similar preparatory result may be obtained by first dipping the textile matters in the lead solution, wringing them, and then passing them through hard water, the lime salts of which precipitate a carbonate and a sulphate of lead. Perhaps a cheap method might arise by the use of lime-water, which, of course, would decompose the lead solution; and, at least, combine with the nitric acid of the nitrate of lead, and form a soluble nitrate of lime. In any case, the presence of any alkaline matter, whether potash, soda, or lime, must be avoided before the articles are dipped into the bichromate solution; because the existence and production of the *bi*chromate depends on an abstraction of a portion of the alkali that is essential to the chromate of potash. This we have already explained at p. 113, *ante*, when stating how the former salt is manufactured for the use of the dyer.

The reason of this will be more evident from the fact that a sub-chromate (the constitution of which is not known) is produced by an abstraction of a portion of chromic acid in producing the orange chrome colours. We have noticed that, when cotton goods have been well worked in a lead solution of the acetate, wrung, and exposed to the air, they invariably gather on their surface a white powder, that must arise from the production of a carbonate of lead (or white lead), due to the action of the carbonic acid in, and partly a constituent of, the atmosphere. If goods or yarns thus treated be dipped into the bichromate solution, to which a little sulphuric acid be added (enough to make the liquor of the acidity, *at first*, of lemon-juice), a fine yellow may be obtained.

We have noticed these difficulties at some length, because of the great value, in respect to brilliancy and permanency, that arises from the use of these chrome dyes: but, from personal experience, believe that there is no method, in the whole art of dyeing, so easy of communicating yellow, and similar good colours, as that found in the employment of lead salts and the bichromate of potass.

One point of essential importance, at which we have already hinted at p. 113, *ante*, must not be forgotten. It is, that all goods should be whitened, as far as possible, before it is attempted to produce these colours on them; as common brown Surat or Madras cotton produces a wretched yellow if dyed in the raw state; but if bleached, the effect is exceedingly good. Another advantage in favour of dyeing yellows by this method is, that the colour produced is absolutely uniform; that is, if all dirt, grease, &c., be absent. No matter what the article, the tint is universally distributed; and hence one of the greatest advantages and highest value of a dye-stuff are ensured.

All colours, from a light lemon to a dark orange, may be obtained by the use of these lead salts and the bichromate of potass. For dark, or rather deep yellows, we have already given instructions. These may be converted into orange, &c., in the following manner:—About one part of sugar of lead to two of litharge are boiled together in three of water (all by weight), for some hours, by which a basic acetate of lead—that is, one containing, practically, less acid than the ordinary sugar of lead, and more lead than that salt—is produced; and a little lime is added to the solution so afforded. The goods to be dyed are well wetted in this solution, and, after wringing, should be passed through lime-water, for reasons already given in the preceding column, when describing a method by which economy may be effected in the use of the bichromate solution. The next step is to pass them through a solution of the bichromate of potass, which should be pretty strong; and all these processes are to be repeated on the goods or yarns until a deep yellow is afforded. To strike an orange on this, a hot solution of lime is necessary; and this must be done cautiously, because of its alkaline, solvent, and decomposing action. Any person who has not been accustomed to this process may easily acquire a modicum of experience by attempting to prepare chrome-orange—a pigment so called, and sold, for the use of painters, at the shops. It is precisely the same substance that the dyer has to precipitate on to the surface, and in the fibre of the goods, by the process we have been describing. Some have recommended the use of soap, oil, soda, &c., with the goods after they have been dyed; but we object to them, on the ground of the possible production of sulphuretted hydrogen, which would certainly spoil the beauty of the colour. For the same reason, the water used to wash them after dyeing must be quite free from every trace of that gas, or injury to the brilliancy of the colour will result.

Green Dyes.—As there is no dye-stuff capable of affording a green dye directly to any textile substance—or, at all events, that can be made of practical use in the dye-house—and as green is, therefore, essentially a compound of blue and yellow dyes, except in the case of a mineral green, produced by arsenic and copper—we shall include the description of the various modes of producing shades of green with the present article on yellow colours; resulting, as they do, from the use of some of the processes described in the present and preceding article on blue dyes. It seems remarkable, however, considering the enormous amount of green colouring matter in vegetable life, that we have hitherto been unable to extract a dye-stuff or colour from leaves, &c. It has been stated that ivy berries, by some peculiar method of treatment, have been applied; but we are not acquainted with

the process. Berthollet remarks—"The green of plants is undoubtedly produced by a homogeneous substance, in the same way as the greater number of hues which exist in nature. This colour owes, then, its origin sometimes to simple rays [see remarks on the spectrum, at p. 86, *ante*], and sometimes to a union of different rays; and some other colours are in the same predicament. Were the greens of plants due to substances, one of which is yellow and the other blue, it would be extraordinary if we could not separate them, or at least change their proportions by some solvent." The colours of the flowers and leaves of plants are caused by two different principles. That of flowers has been termed *chromule*, whilst that of the leaves is called *chlorophyl.* It is somewhat remarkable that the juice of most red flowers affords a blue liquid when expressed from them; and the colour is so delicate as to be instantly changed to a red by the slightest quantity of acid; even carbonic acid being abundantly strong enough for this purpose, although, apparently, in exceedingly minute quantities in the colouring cell of the flower. When a petal is rubbed the cells all break up, and the red colour is lost by the escape of the carbonic acid gas. We know, similarly, that litmus may be used as a test for acids; and is thus largely employed in the chemist's laboratory, as it becomes instantly reddened in contact with an acid. Similarly, we may suppose that the red of flowers, of the rind of fruit—as the plum, &c.—is caused by this power of converting blues to red possessed by acids.

The *chlorophyl*, or green colouring matter of the leaves of plants, may be separated by bruising the leaves in a mortar with water. The mass so formed is to be transferred to a funnel, and allowed to drain off all liquid possible. It is then pressed dry, and boiled in spirits of wine carefully to dryness. The mass thus left gives a green colouring matter to water when stirred up therein, and this colour is the chlorophyl. It is distributed in plants on the tissues, but more particularly on the surface of the starch cells, which are abundant in all green plants. It is necessary for its production that the plant be exposed freely to light; hence the rich deep green of many tropical plants. On the other hand, if light be carefully kept from a growing plant, its leaves become blanched; hence the method of producing white leaves, or hearts, in lettuces, celery, endive, &c. It will be familiarly known to all our readers, that onions and potatoes which have sprouted in the dark have the stems and leaves quite white. Some years ago Sir John Herschel made some most interesting experiments on the photographic character of the green, and other juices of plants; and he distinctly showed that sun-rays act in precisely a similar manner in producing colour, whether of the leaves or flowers, as they do on the sensitive plate of the photographer, when exposed to their action. Now, this result arises from certain chemical agencies; and some simple but valuable experiments may be made, that are instructive even to the practical man, and very interesting to all. First, for example, if some common cress be grown in the usual manner, but under a yellow or red glass cover, the plants grow up sickly, and of a pale hue; whilst if placed under one of blue, through which the chemical rays of light readily pass, the plants flourish well. The reason of their not doing so under the yellow or red glass is, that these keep away the chemical rays, and so prevent the action essential to rapid and healthy development. Again, it is evident that the cause of the green of a healthy leaf is due to the vital action stimulated by solar rays, through which the oxygen of the carbonic acid they absorb is given off, and the acid character of that acid destroyed. When, however, the leaf is separated from the tree, and that vital action stopped, it gradually turns brown or red, owing to the conversion of its chlorophyl by the carbonic acid at once produced in the cells by chemical decomposition. Now, the acid acts on the green colouring matter, and turns it red; but the previous colour may be restored by the addition of a little alkali.

We have made this divergence from the practical part of our subject for the purpose of explaining how it is we cannot hope to obtain a green dye from the leaves of plants, although we get others from flowers; as, for example, safflower, saffron, &c. But the latter, when separated from the plant, and dead, retain the colouring matter, or have the previous one converted into that subsequently possessed. Not so with the leaf, which speedily loses, as we have seen, by chemical action, its characteristic colour; and hence becomes valueless as a dye-material.

Stuffs to be dyed green are sometimes coloured first blue; and, at others, the yellow is first communicated. Thus, in dyeing greens with fustic, they are first blued by chemic, or the blue vat (see *ante*, p. 139); afterwards washed and mordanted by the acetate of alumina, and then passed through a hot bath of fustic. The strength of both the indigo and fustic liquors, the length and number of immersions, regulate the depth of colour imparted.

In a similar manner, when chrome is used as a yellow ground, the article is first dyed yellow by methods already detailed, using, however, the acetate, and not the nitrate; because, as we have already shown at p. 143, *ante*, the acid of the nitrate tends to redden or deepen the colour to an orange; and greens are composed of pure yellow and blue, and an entire absence of red. A reference to p. 86 will at once show why this is the case; for we there stated that the green of the prismatic spectrum is between the blue and yellow, and not on the red side of the latter.

Many modifications of green, in respect to shade, brilliancy, &c., are obtained by using various yellow grounds, derived from other dye-stuffs than those we have enumerated. But it will be unnecessary for us to go into any details of the subject, as the principles and main points of practice are all but identical in each case. For all light greens it is desirable that the material, whether cotton, wool, or silk, should be as white as possible; hence the necessity of the operation of bleaching or scouring, in such cases,

before dyeing. Brown-coloured cotton, in yarn or cloth—as, for example, that from the East Indies—never takes a rich green, but always has a dead or saddened appearance. Hence, in its case, bleaching is essentially requisite. Some kinds of goods, made from American cotton, are occasionally white enough for ordinary greens.

In respect to green entirely produced by mineral substances, we have already animadverted on their production, if arsenic and copper be employed, at pp. 113 and 116, and need not again refer to the subject. The colour thus produced arises from the union of arsenious acid and copper, forming what, in chemical language, is called an arsenite. It will be, therefore, seen that the dye results from a definite chemical combination, analogous to Prussian blue and the chrome colours, in all of which the best effects take place in the union of equivalents, or chemical combining proportions—a law of the science that we have already in part explained.

There is one matter of great practical importance to the dyer in relation to colours produced by mineral agents; and that is, if the dyeing operations are properly conducted, there is produced, on the surface of the material, a kind of bloom, far superior in brilliancy and attractiveness to the eye than those afforded by vegetable colours alone. This may be readily seen by contrasting a blue dyed respectively with indigo and Prussian blue, or a yellow dyed with fustic, and one with chrome. Aniline colours have a similar advantage; and this has, to a great extent, brought them into such great use.

Black and Gray Dyes.

We have already noticed the remarkable fact that we possess no dye-material that will afford a black dye or colour *per se*, with the exception of certain of the Cashew-nut order, or *Anacardiaceæ*, that, practically, are valueless for the purpose; hence all kinds of blacks must be produced by the union of tannin or astringent matter, and oxide of iron presented in some convenient form. At first sight such a process would appear easy; but, in reality, nothing is more difficult than to obtain a good black, according to dyeing phraseology.

But really, and in a scientific point of view, such a colour as black has never yet been obtained by the dyer's art, nor does it exist in nature; for the hair of man and the inferior animals, the feathers of birds, such as the raven, and, indeed, all other apparent blacks produced in nature, are either shades of blue or brown; or, perhaps more correctly, at least more popularly, are either blue-blacks or brown-blacks.

According to optical laws, as generally received, and almost in the words of the celebrated Sir Isaac Newton—"The colours of bodies are not qualities inherent in the bodies themselves, by which they immediately affect our sense; but they are mere consequences of that peculiar disposition of the particles of each body, by which it is enabled more copiously to reflect rays of one particular colour, and to transmit, or stifle, or, as it is called in optics, absorb, the others."

From this definition of colour, it follows that, philosophically, black is not a colour. On the contrary, it should be defined as "no light;" or, in other words, we must consider it such a condition of bodies as that in which, if of an absolutely pure black, they reflect neither coloured nor white light to the eye. Indeed, we presume that, in such a condition of a body, it absorbs all the rays, and neither transmits nor reflects any. Shortly, therefore, we may define black as a negative of light.

If the practical dyer will carefully consider what we have here stated, he will at once perceive why it is that he can never, by all the art he may exercise, or all the materials he may employ, produce a true black. And this will be all the more readily perceived by trying two very simple experiments. If a magnifying-glass, having a convex or projecting surface on one side, and a plane or flat one on the other—that is, what we call a plano-convex lens—be pressed on the surface of a piece of perfectly flat plate-glass, the projecting part of the lens resting on the flat plate, a series of coloured rings will be produced, having a *black* centre. The first ring is formed at the point at which the lens and plate-glass apparently touch each other; but at this they are separated by a film of air, so thin *as to be capable of reflecting no light to the eye.* The succeeding colours in this first ring are blue, white, yellow, orange, and red. About seven of these rings may be observed, and in these most of the colours with which we are familiar may be seen; but, for the sake of simplicity, we shall omit further notice of them. A similar result may be noticed in blowing a soap-bubble; but, for practical study of this phenomena, the following plan may be adopted:—

Into a white, thin glass bottle, or, still better, a Florence flask, put a piece of Castille soap of about the size of a large pea, and a wine-glassful of water. Place the bottom of the flask in a saucepan of water, which is to be boiled. After a time the water in the flask will also boil; and when it sends forth abundance of steam insert a cork that shall entirely close the neck. Remove the flask, and cover the end of the cork with sealing-wax, so as to prevent the possibility of air entering. When the flask becomes cool, by a little shaking a film of soap may be made to reach right across the inside of the flask, where it will remain for a long time, being first of a red colour; and after passing through all others of the spectrum, till it arrives at a violet, it will become "pitchy" black, and then break; because it is then both too thin to reflect light to the eye, and even long to exist.

Now, without entering into any mathematical proof of what we are about to state, and which would require, on the part of our readers to understand, an extensive knowledge, at least, of trigonometry, it may be taken as a well-established fact, that the thickness of the plate of air, at the point where the central black spot appears between the lens and the glass plate, does not exceed the one hundred and eighty thousandth

part of an inch in thickness; or, in figures, the $\frac{1}{180000}$th of an inch.

We now refer to our remarks on the thickness of cotton fibre, given at p. 12, *ante*, where we shall find that it varies from $\frac{1}{500}$th to $\frac{1}{2000}$th of an inch in diameter; or, taking an average of $\frac{1}{1250}$th of an inch, we shall find that the cotton fibre has a diameter equal to 144 times that of the plate of air, which affords no colour, or black, scientifically considered.

It therefore follows that a dye-stuff, if of itself absolutely productive of black, has to deal with a surface impossible, individually, of reflecting no light to the eye; and over which the colour, whatever it may be, must necessarily be spread unevenly. Now, wherever this occurs, there cannot be any colour produced absolutely the same as that so called in the spectrum; because, as we have seen, different thicknesses of films present different colours to the eye. It is for this reason that we perceive, on the surface of mother-of-pearl, that beautiful play of prismatic colours, with which all are familiar. These are caused by minute cracks, that reflect to the eye such a colour as is consistent with those produced by the thickness of films, shown by the ring of the lens and plate, and those of the soap-bubble. The colours of the mother-of-pearl may be, indeed, transferred to black sealing-wax, which, presenting of itself little coloured light to the eye, readily reflects those that may be seen on its surface by the transference of the cracks of the mother-of-pearl to it. Several years ago, a philosophical adaptation of these facts was made to prove their source. Barton's buttons are what we now refer to. They consisted of a piece of polished steel, on which were drawn exceedingly fine lines, corresponding to the thickness of air-films produced by the lens and glass plate. The same effect is often produced by rubbing a polished metal surface with a cloth not quite clean, when either moisture or dust, the first by deposition on, and the latter by scratching the surface, induce similar results.

From what we have stated, it will be perceived that it is impossible to produce, on any textile surface, any colour true to that of nature by the art of dyeing. We may approximate closely in red; less so in yellows; still less in greens; less again in blues; and least of all in blacks. A careful study of the reason of this, however, instead of causing disappointment or discouragement, should rather stimulate to fresh attempts, in which a nearer approach to success may be reasonably hoped for, provided science be our guide.

Parenthetically, we may, perhaps, be allowed to express the opinion, that the beauty of the aniline dyes may be in part due to the excessive fineness of the particles of which they are composed. In common terms of speech, "a little of them goes a long way." Hence we must conceive, that not only are the particles very minute, compared with those of vegetable dye-stuffs, but that they are more equal in size; and hence, when communicated to stuffs, afford more even, and therefore brilliant, tints. We offer this, however, merely as a speculation of our own. It is not given as a *fact*, in respect to cause. We merely deduce such opinions from consideration of those laws of light to which we have at some length drawn attention. Our object in writing this work is not to tell the practical dyer what he ought already to know far better than ourselves, but rather to communicate such information which we conceive ourselves to possess, and believe that he lacks.

There is, however, one substance in nature that approaches in "colour" (and now we leave scientific, and turn to practical phraseology) to an almost perfect black; and that is pure charcoal. We do not mean the charcoal used in furnaces, and obtained by burning wood, or from bones, as in animal black; nor even lampblack, although the last is the blackest of all. The charcoal we refer to is obtained by entirely different means, as follows:—Dissolve some white (loaf) sugar in hot water, so as to give a thick syrup; and to this add some of the strongest sulphuric acid. The latter will abstract from the sugar its water; for sugar is composed entirely of carbon, or pure charcoal and water. The liquid will rapidly froth up to eight or ten times its previous bulk, and a spongy black mass is obtained. If this be well washed with water, first hot and then cold (and, in both cases, distilled, and not river water; for this will contain various impurities), the practical man will procure a mass of about the blackest substance that natural objects can afford; and, to a certain extent, may use it as a standard of comparison, and as a model for emulation in dyeing processes. Of a similar colour is charcoal, occasionally found in lumps of coal, having not as yet undergone complete mineralisation.

So much for what we may call the philosophy of "blacks." We now turn to more practical considerations.

Two chief materials are necessary in dyeing a good black; the one being a proper salt of iron, and the other an equally proper source of tannin, or astringent matter. The difficulty arises, not from want of sources of either, but in the selection of them.

At p. 106, *ante*, reference has been made to numerous sources of tannin, such as galls, sumach, logwood, catechu, myrobalans, kino, &c., either there named, or previously described in the list of vegetable dye-stuffs. Practically, galls, sumach, alder, and logwood, are most employed. Galls, from their expense, are chiefly confined to the purpose of dyeing silk; whilst, of the rest, sumach and logwood are most in request. Still turmeric, quercitron, fustic, and a host of other stuffs contain tannin, or astringent matter; and hence may be used in producing a black on various kinds of goods.

It must be borne in mind, however, that all these substances have, more or less, an independent colour of their own, and that not one of them is black. Thus the natural colour of turmeric, fustic, quercitron, &c., is yellow; log, and other similar woods, as Brazil, &c., are naturally of a red, and, in certain cases, afford fine red dyes, with a mordant of tin or alum. But

logwood, with an iron mordant, can be made to produce a blue-black; whilst sumach has a tendency to afford a brown-black. It is possible, therefore, to unite the conditions of both, and mixing the blue with the brown tendencies of the individual stuffs, we may arrive at the production of what the dyeing world calls a good black.

In respect to the oxide of iron, it must be remembered that tannin gives no precipitate with the protoxide, but a blue-black with the sesquioxide. The difference of these two states of oxidation in iron, and its reason, have been already pointed out at p. 112, *ante*, under the head of Iron, as a chemical and a mordant.

But, true as the chemistry of the process is, it does not follow that the iron should be employed direct from a persalt in dyeing black; if this be done, the good colour at first obtained soon disappears, and the goods or yarn become of a slaty colour. It is hence advisable to use a protosalt, such as the sulphate or copperas, or the acetate or pyrolignite, both described at p. 112, *ante*. The last is, for most purposes, the best, because the acetic acid has less attraction for the iron than has the sulphuric in the sulphate or copperas. A rough acetate, formerly, if not now, much used, was formed in large quantities in the dye-house, by filling an old vat with waste iron, alternate with alder bark, or other inexpensive astringent matter, together with water, by which the iron was gradually dissolved, and formed what is called iron or black liquor.

Generally speaking, in dyeing cotton, both sumach and logwood are used as the astringent agents. Various methods have been proposed for extracting their astringent properties, or tannin, which is usually employed in a heated condition. Logwood is supplied to the dyer in the form of chips; but it is highly advantageous to have it in a coarsely-broken state, not powdered, for then the hot water acts more readily on it, and more fully extracts all soluble matter. It may be put loosely in coarse gunny bags, tied at the neck, and suspended at the *top* of the vat in water heated by steam. The reason of placing it at the top is, that all dye solutions are heavier than water, and hence the lower parts become saturated, whilst the upper are scarcely tinged with colouring matter. This can never happen if the plan we propose be adopted. The same method may be employed in making the sumach decoction. Another and most slovenly, but very common, way was to boil the dye-stuff loose in coppers, to the bottom of which it eventually fell; but it is impossible to keep the goods from becoming mixed with the woody rubbish if this plan be adopted. We have used it in large tanks heated by steam, and then gently sunk hurdles on to the surface of the waste wood that falls to the bottom, and so prevented any mixture of them with the goods. As our operations were on a much larger scale than that which many of our readers will perhaps follow in dyeing black, and tanks holding some thousand gallons of liquid, and oblong in shape, being employed, that facilitated such a method, we recommend the first method as a general rule—that of putting the logwood or sumach into coarse bags suspended at the top of the liquid, as being the easiest and readiest of adoption. The liquor, again, may be made by boiling the chips in one vat, and drawing it off, before use, into another, so as to prevent admixture of any sediment. We always used high-pressure steam, of thirty-five pounds on the square inch, to boil the water, and about six hours was required; after which the liquor was left till next day, with the bags still suspended, so that all available matter might be extracted.

Another and ingenious mode was proposed some years ago, in which the shavings of logwood were placed in a vat with a false bottom, raised to a height of a few inches. Steam was then admitted at the bottom, and allowed to pass in until it began to appear at the top. Water was then added, and allowed to soak the shavings for some time; and it was afterwards drawn off from the bottom of the vat by a cock, the false bottom above which prevented the outward passage of any shavings. The process was repeated until the wood was exhausted as much as possible.

An ingenious plan, somewhat similar to a common method of making coffee, has been also used. It consists of a metal vessel, into which the chips are thrown. Over these a metal cover, pierced with holes, is firmly fixed. Boiling water is then forced in by a pump at the bottom of the vessel, and must, in its passage upwards, pass through the logwood. Thus the strength is gradually extracted. A modification of this may be made by having a vessel capable of sustaining a vacuum, which can easily be produced by first filling it with steam, and then condensing this by cold water. At the top may be another vessel holding the chips, and into this boiling water, if poured, may be forced through by atmospheric pressure.

Any or all of these methods are equally available for any other dye-stuff; but their choice we must leave to our readers; and we have no doubt that many of them will not only avail themselves of what we have stated, but, very probably, effect considerable improvements. Indeed, there are several other plans in use; but we must not burden our pages with their description. A very rigid regard to scientific principles, most of which, that are applicable to the dye-house, have been already mentioned in the earlier part of this work, will not only facilitate the operations of the dyer, but, at the same time, effect a great economy in his expenditure for dye-stuffs—matters of the utmost importance in all commercial operations, and that also tend to foster a general, proper, and judicious management throughout the entire concern, whether we regard master or man; for a very little carelessness and neglect, on the part of the employer, open the floodgates of license, that is soon taken advantage of by those with whom he has to do.

It will be unnecessary to inform any of our practical readers that the quality of all kinds of woods—indeed, all dye-stuffs—is liable to constant variation. The length of the growth of

the tree or shrub, the period of cutting, picking, &c., and the nature of the seasons, &c., all influence such a question. It is hence so difficult to give exact directions as to quantities in respect to the extraction of colouring or other matters obtained from such sources; experience, therefore, must, as a rule, be the best guide.

At an earlier page (112) we mentioned that an opinion is prevalent that hard water (with certain limits) is advantageous in dyeing black; and we shall now quote, *verbatim*, the opinion of one to whom we have been already more than once indebted for practical remarks, combined with much scientific knowledge. We are the more pleased to do this because the circumstances and assigned results that he describes, have not, practically, commanded our notice when formerly engaged in dyeing operations. He remarks—

"Another thing which modifies the results of these experiments (on the action of tannin on iron salts, both *proto* and *per*) in their application to dyeing, is the quality of the water used. If the experiments be performed with distilled water, it will be found, on repeating them with common spring water, that one-half the quantity of stuff will give the same depth of colour; and that the colours, in this instance, have more of a purple hue, and are much more permanent. This may be illustrated by a very simple experiment. Thus, take two jars of equal size, fill them half full of distilled water, and add an equal quantity of a solution of galls or sumach; put into each an equal number of drops of a solution of protosulphate of iron (copperas); the change of colour is scarcely perceptible: but fill up one to the brim with spring water, and it almost instantly becomes a dark-reddish-black. Allow both jars to stand for an hour, and the solution, with the distilled water, will have become a deep violet; while the other, notwithstanding the double quantity of water, is so dark that no light is transmitted; and it will require one-half more water to reduce it to the same shade as the other, but still *retaining more of the reddish hue, which, by the way, makes it superior for blacks.* [The italics are our own, and the sentence will be again referred to.] It will be also found to be much more insoluble, and requires a greater portion of acid to decompose it. If soft, or filtered river water, be used instead of distilled water, the distinction is not so great; but still the difference is equal to one-half. The best water which the writer has experienced for dyeing black and other saddened colours, gave, by qualitative analysis, carbonic acid, lime, silica, iron, sulphuric acid, and muriatic acid. The whole solid contents did not exceed one grain in a fluid ounce. These ingredients probably existed in the water as sulphate of lime, carbonate of lime, muriate of lime (chloride of calcium), and carbonate of iron. The iron was in very small proportion; the carbonic acid and lime the greatest. Now a dyer learning his trade in a work where such a spring was used, could not fail to become a successful dyer of all saddened colours; but were he taken from this work to another, where soft filtered (river) water was used, what would be the result? When he attempted to dye a black with the same quantity of dye-stuff he formerly used, he would only produce a dark slate colour; and if he wished to obtain a slate colour, he would produce a gray."

Now, no doubt, much truth may be found in the remarks we have just quoted. There is, however, one point to which we must refer; and that is, that *proto*sulphate of iron does not give a precipitate of a blue or black with tannin, but this does with a persalt of iron. If the spring water he used contained much air or oxygen, which it very possibly might have done, an effect of peroxidation of the iron would take place, and precisely the results he named, and especially those that we have marked with italics, would have arisen. Making every allowance, therefore, for all that has been urged, and also adding that river water would, although perhaps possessing less free air than spring, yet have far more than distilled water, we cannot help considering that he has left out this one, and serious, element in his calculation—the oxidising effect of air or free oxygen in the water of the spring.

We may now refer to the usual method adopted in dyeing cotton, silk, &c. In respect to cotton, of course it needs no bleaching, but may be dyed in the raw or brown state. There is one point, however, that we have not seen recommended in practical works on dyeing; and that is, the necessity of removing some of the resinous matter, of which we have already spoken. Having had much to do with the dyeing of both cotton, wool, and yarns, we need scarcely say, that it was a matter of necessity always to hasten the process, and economise materials. We have already frequently called attention to the preventive influence that the resin coat of cotton has against the action of either dyeing or bleaching agents; and as it is impossible to produce a good white in bleaching until that has been removed, its absence in dyeing black is just as desirable. It will be sufficient to introduce the yarn, or goods, into a moderately strong, but hot, ley of soda, or, perhaps, lime, for some time; after which they should be well washed. They may then be worked for some time in the sumach, which should be hot, or left to steep therein for some hours; but the latter method is not so effective in thoroughly introducing the liquor to every part, because the external threads of each hank hide the inner from its action. It is better, therefore, to work the hanks individually, if not constantly, at least occasionally, in the first bath. They may, on removal, be thrown on a hurdle, so that superfluous liquor shall run from them. They should then be run through lime-water; again thrown singly on a hurdle, and, shortly afterwards, worked in the iron liquor, either of copperas, or, preferably, of acetate of iron. On removal from this, they should be either wrung or left to drain for some time on a hurdle; and, subsequently, each hank should be shook, so as to open its threads, and allow of free access of air. They thus become black, but not of a suf-

ficiently deep shade. By passing them through weak lime-water, draining, and then using a bath of logwood, the colour will be better fixed. Some persons add to the logwood a little sulphate of copper, or verdigris, which is said to improve the hue; in any case, it is advisable to add some copperas, otherwise the tint of the logwood will give the yarns a reddish appearance. Abundant washing, to free from all acid and superfluous dye-stuff, and subsequently drying by steam-heat, complete the process.

Such is a general outline of the usual method of cotton yarn dyeing for black, and is what we may term the "regulation" method; but some matters of importance connected with it require remark. Many years ago, while dyeing cotton waste, in which there was much oil that had been gathered from machinery, we noticed that the oily cotton took the dye infinitely better, and had a far deeper shade, than that which was free from oil. Of course, the oily waste, although cheaper at first cost, became dear in dyeing, owing to the quantity of iron, logwood, and sumach it appropriated; and, for purposes of economy, it becomes necessary to free it from the oil by boiling in soda. The occurrence, however, led us to try numerous experiments, a *précis* of which we have not now, owing to destruction, by fire, of that and many other papers some time ago. But by memory we may state, that a very rich full black can be obtained by using oil diffused through the yarns to a small extent. We tried the experiment on some doubled 180s. cotton yarn. It was first boiled with soda, to free it from resin, and cocoa-nut oil that had been added to give it gloss in the brown state. The sumach bath was its next destination, in which it was left for several hours. It was next passed through weak soda ley, and carefully washed; then aired, and subsequently worked in a solution of acetate of iron; again aired, and washed. A little olive oil was poured into some hot water, and in this the yarn was well worked for some time. The sumach bath was again had recourse to; and, subsequently, one of logwood, to which copperas was added. After washing and drying, the black was so rich as to well match black silk in lustre and colour. At the time we refer to, this fine class of doubled cotton was largely used to back velvets, as it was considered that it produced a better selling article than one made entirely of silk.

So far we have given, from memory, the method and results then adopted; but in dyeing cottons of a black, we cannot help noticing the uncertainty that generally exists in getting a really good colour. About thirty years ago, we employed some of the leading dyers in London, Derbyshire, and Lancashire, in producing blacks on No. 14s. and 50s. mule-twist cotton yarn; and although each was supplied with a portion of the same hank, already dyed black, as a pattern, no two parcels of the goods were alike on their return. The price asked by each dyer was cheerfully paid; and hence no motive of false economy prevented proper and promised results. Some smelt strongly of fustic, and these were certainly the worst specimens; whilst those in which the smell of logwood could be discerned were by far the best and richest in colour.

We may add, that if we were asked at this moment, and tempted with the greatest pecuniary consideration, to say how the best black is to be produced on cotton, that should be invariably successful as to depth, richness, and permanency of colour, we should have to frankly confess the impossibility of a definite answer. We have heard and read much dogmatism on the matter, and positive assertions as to the propriety of a special method; but a good black on cotton yarns, that could be equally produced by any dyer, if instructed in its details, is as yet, so far as we can judge, as distant from attainment as malleable glass, the artificial production of the diamond, or the philosopher's stone.

In regard to piece goods of cotton, we need say nothing further than that all the chemical operations are identical with those involved in yarn dyeing: the mechanical details chiefly vary; and as these are common to every colour, and have been frequently noticed, we need not again refer to them.

All kinds of textile fabrics largely increase in weight when dyed black; hence the process of weighting silk by tannin matter, which, for cheapness sake, is obtained from sumach. Galls are, however, a frequent source of astringent matter in silk dyeing. All our practical readers will know the extent to which the weight of silk may be thus increased. As regards cotton yarns, we have noticed an increase of weight, so that a ten-pound bundle will sometimes be returned eleven to even twelve pounds in weight. On one occasion, a "knowing" dyer offered to produce an excellent black at the rate of a penny per pound. He was intrusted by us with 500 pounds; that is, fifty ten-pound bundles. On these being returned, they were put through the scale; and they were found to weigh exactly what they did when he received them. Thus, by abstracting at least 10 per cent. of the cotton, which the increase by weight of dye permitted him to do, and yet allowed him to return the original weight, the yarn cost us really two shillings per pound. Of course, his first trial, on our part, was also the last.

Silk readily takes a black dye; and, in certain respects, jute, a species of Indian hemp, resembles it. It is usual to dye sheep's wool, yarn, worsted, and cloth, blue first, by means of indigo, when a full-bodied black, especially of a blue tint, is required. In any case, even for cotton, such a method is advantageous; for in piece goods, the blue, like charity, hides a multitude of sins, or defects, that so frequently occur in producing blacks. The Prussian blue may be, for the sake of economy in many instances, substituted for the blue vat, or chemic. In its use, however, precaution must be taken in reference to leys of potash, soda, lime, &c., all of which, as previously noticed, will decompose the dye—that is, the iron salt—and destroy the colour.

We must here notice, that all infusions or baths containing tannin, or astringent matter,

are liable, after a time, to a change, that much diminishes their value. The chemist is well acquainted with the fact, that by exposing nut-galls in powder to the action of air and moisture, the tannin, or rather the tannic acid they contain, is converted into gallic acid; and, indeed, for a long time this was the chief method of producing the latter substance. The cause of this change is due to the oxidation of the tannic acid by the action of the oxygen in the atmosphere. Now gallic acid, although it produces a similar colour, with the sesquioxide of iron, to that afforded by tannic acid, is not so permanent; and not only so, the acid is barely soluble in water; and thus, if it could produce as good and permanent a colour as tannin, it would be all but valueless in dyeing, because so little of it would be present in the bath. Now, it unfortunately happens that a sumach bath which contains much tannin, gradually undergoes a similar change to that we spoke of in respect to the nut-galls. It absorbs oxygen from the atmosphere; and, as such, soon passes into a comparatively useless state. Another evil arises from this; which is, that when gallic acid is present in a bath, the colour of black afforded by the entire process of dyeing is much inferior. At one time we were in the habit of constantly using the same liquor, replacing water abstracted by the goods from the trough, and keeping up the strength by fresh decoctions of sumach. We first learned the error of this by noticing that the cotton, with the same quantity of all materials, in each successive dyeing got less black, until, at last, only a dirty slate was produced. At first we looked to the workman for its cause; but we were assured that it was no fault of his. The trough was accordingly cleaned out, and a fresh bath made, and all difficulty vanished.

Logwood baths are equally the subject of changes, that pass on until something of the nature of putrefaction becomes apparent, especially if any greasy matter, or oil, or soap, has found its way in. The stench thus produced at last works a cure, for no man could work over a trough containing such a decomposing solution, especially whilst being heated. Rough, indeed, as are the operations of the dye-house, compared to those of the laboratory, still the same precautions are requisite in each, as cleanliness, system, and order; and attention to these points may often become the preventive of annoyances that it would be difficult to account for on known grounds; because, generally, the causes of so-called "accidents" are not easily found out or distinguished.

Gray Colours.—In dyeing these colours we invert philosophy in practice. Scientifically, we consider gray to be a modification of white; but, in the dye-house, practice teaches a directly opposite course. Gray-production, in respect to ordinary operations, may therefore be considered as a diminishing of the tint of blue-black to almost any extent, approaching a white; in fact, at a distance from the objects, one of blue and one of black, rapidly revolving and interlacing each other, produce a gray colour. If on a card the prismatic colours, violet, indigo, blue, green, yellow, orange, and red be painted, and the card be fixed on a pivot, and rapidly revolved, gray tints are at once produced. Therefore, in science, we say gray is a modification of white.

Practically, blue dyes of a faint character are good sources of gray, slate, lavender, violet, and allied colours derived from black. Hence orchil, and many other lichen dyes, are convenient dye-stuffs for producing such colours: they are especially of value in dyeing silk of such colours. In regard to cotton, logwood, and an acetate of iron mordant, are very commonly employed. Sumach is also of use for the same purpose; the effect depending on the union of a small amount of tannin with the sesquioxide of iron.

It is impossible to give directions as to the relative quantities of mordant and astringent bath that should be used. But one point of considerable importance may be mentioned. The oxide of iron, if too plentifully distributed on the cloth, will, of course, produce a black with tannin or astringent matter. But as the oxides of iron are soluble in any of the mineral acids, it lays within the power of the dyer to regulate the shade of gray when logwood, sumach, &c., are used with the iron mordant.

For example, if too deep a shade has been produced, sulphuric acid, abundantly diluted with water, will remove the oxide of iron from the fabric, and, with it, the astringent, or tannin. No matter how dilute such a solution of the acid may be, it is requisite that abundant washing in water should subsequently be had recourse to; for, as we have repeatedly had to remark, sulphuric acid has a most destructive effect, especially on cotton goods, converting them, by its action, occasionally into grape sugar. A pound of cotton or linen will thus yield more than its own weight of sugar, at the expense of the tenacity of the fibre.

Wool and silk are more easily dyed of any shade of gray than cotton, because they "take" colour far more readily, and are therefore under better control. Generally speaking, in dyeing gray, galls, sumach, and catechu may be employed as astringents, with an acetate of iron mordant.

Red Dyes.

As a general rule, any and every shade of red have been favourite colours of our race from the days of the Tyrian purple to our own, when coal-tar dyes have produced such brilliant results of the art. Why such should be the case we can scarcely understand, considering that the optical requirements of the eye are much better satisfied with colours in which blue is the chief constituent. Fashion and fancy, however, have ruled in that respect; and, despite that the glowing red colours of the sunset have the effect of inducing contemplation, and even sadness, in most minds; when the same hues are produced on the garments of the emperor, or on the cotton cloth of the wild Indian, the effect is identical. They suggest something fierce, energetic, con-

quering, whether the object of conquest be the heart of the humble village swain, or to dye acres of ground with the "life" of humanity. Red is a colour, therefore, by the prescription of antiquity, sacred to all that ministers to pride and passion.

We need not, therefore, wonder, that for the last three thousand years at least, and how much longer we cannot tell, the art of the dyer has been devoted to producing the richest tints of what we call red. But the dyer has not been sole in such efforts. In glass-staining, for example, a rich ruby has, for many hundred years, been as ardently sought for. The horticulturist, similarly, has all the knowledge of his art called out to please the fancy of our eyes; hence a rich tulip, fuchsia, geranium, &c., &c., command a price almost as high as their weight in gold.

Another and important matter, in respect to colour, is the fact that the shades of red are almost innumerable, simply because pure red blends with each of the primary colours. Thus, with blue we have purple, violet, and many other colours, with which all our readers must necessarily be well acquainted, independent of those of recent origin, arising from the use of the coal-tar series of dyes, and commencing with Magenta. Indeed, the fancy that the eye may indulge in, respecting varieties of red shades and tints, is only equalled by the numerous perfumes that flowers afford us—so bountiful has nature been in providing for the gratification of at least two of our senses.

The dyer has no reason to complain of any paucity of sources for producing any desired effect in respect to such colours, for he has the most extensive choice in regard to the materials he may employ. Animal, vegetable, and mineral life all tend to aid him; and hence it is simply left to the exercise of this art to limit the number of pleasing colour associations that may be desired.

It will be convenient that we should take in proper order some of the chief sources of our red dyes; and we shall therefore first deal with those that are derived from plants. First in order must be safflower, which, of all other dye-stuffs, affords the richest shades of red, rose, pink, &c.

As already stated, safflower is a native of climates bordering on the tropical, and extending from China, across India, to the south of Europe. Botanically, it belongs to a natural order, the Composite, or *Compositæ*, rich in products, valuable in an economic point of view, and one of the largest and best-defined families of the vegetable kingdom. In our own country, the hedge-side dandelion is a well-known illustration of such plants. The flowers, as imported into this country, have a dirty-red appearance, showing little signs of the beauty of the dye that may be derived from them by proper, but very careful treatment. And here we may notice one especial point in reference to the dye-colour of safflower; and this is, that a low temperature is essential for obtaining it in perfection. Even the heat of summer, in this climate (south of England), greatly militates against its production, so delicate is it in regard to the effects of heat.

Two colours, yellow and red, are obtained from safflower, the former being soluble with ease, and the latter barely, if at all, soluble in water. It must be remembered, however, that the insolubility of the red is liable to modification. Thus, if safflower be put into a bag made of any vegetable fibre, but especially of cotton, and beaten in water, although, so far as we can judge, none of the red matter will float away as a solution, still the material of the bag will absorb much of the red colour, which so far becomes practically lost to dyers. It is found, then, that if, whilst the safflower is being beaten in water, a piece of cotton cloth be placed in the bag, it gradually acquires a red colour; hence the importance of avoiding, as far as possible, this cause of loss, will therefore be evident.

The yellow colouring matter is useless to the dyer; and as it constitutes a considerable portion of the weight of the safflower, it becomes a serious cause of expense, or rather, so far raises the cost value of the dye-stuff.

At the present day, large quantities of a kind of extract from safflower are sold, especially for dyeing silk of rich rose to colours of a pink tinge. It is, as far as we can ascertain (and we have some reasons for speaking *ex cathedrâ* on the subject), procured by withdrawing the colouring matter first imparted from the safflower to cotton, and rendering it of a rich blood-red colour by the action of citric acid. The cotton is first saturated with the colouring matter, which is then withdrawn by an alkaline solution. The process, therefore, in nowise differs, as regards the production of red from the dye-stuff, as followed in dyeing, except that the colour, instead of being left on the stuff, is produced in a liquid condition. For many years much of this liquid was prepared at a factory near Upper Clapton, on the banks of the Lea, near London, under the care of a French gentleman; and for a firm in London, who largely supply silk dyers with the liquid extract of safflower, or carthamin (see *ante*, p. 101).

If safflower be employed directly for dyeing either silk or cotton, it is first requisite that all the yellow matter be removed by abundant washing, in a running stream if possible; if not, by water constantly running, though by more artificial methods, because any portion of the yellow colour will certainly dull, and therefore spoil, the fine, rich, rose-red tints obtainable by care from this dye-stuff. Our advice is, to put the safflower into a tub, at the lower end of which is a false bottom, pierced with as many holes as possible, made by a small gimblet. This false bottom to fit lightly to the sides of the tub; and if all exposed parts be pitched over, so as to prevent exposure of the woody matter, so much the better; because cotton, which we have seen rapidly absorb the colour, does not, practically, greatly differ from ordinary goods in that respect. The safflower being placed on this false bottom, should be covered lightly with a piece of wood, or, still better, wicker-ware, held down by a weight. Water should be allowed then

to freely flow through the safflower, which at times may be stirred up, so as to present new surfaces for action of the liquid in removing the yellow colouring matter. Occasional pressing is of great advantage, so as to drive away all liquid saturated with the yellow solution.

We have already noticed that a low temperature is essential to the whole process of producing the red colouring matter of safflower; and so important is this in preparing the "extract" used for silk dyeing, that the parties to whom we have already referred, as having been the largest manufacturers in this kingdom, always suspended operations after the end of April, till the beginning of October.

After the yellow colour has been entirely removed—and it will require at least thirty-six to forty-eight hours to effect this—the safflower should be removed, and placed in another tub, the bottom of which is pierced with holes. On its upper surface a board may be placed; and on this weights, so as to drive off, as far as possible, all moisture: but in doing this the mass should not be allowed to dry. Meanwhile, another tub should be prepared, in which about one-sixteenth part of carbonate of soda should be dissolved in thirty parts of water, to one of safflower, *all by weight*. The alkaline carbonate having been dissolved, the already-washed safflower is put into it, in the proportion above stated; that is, about one pound to thirty of water. The safflower should be well stirred about, so as to secure the full action of the alkaline liquid, in which the red colouring matter is soluble. So far as we have seen, not less than twenty-four hours' action, aided by repeated stirring, is requisite to extract fully the red colour. The liquid is then to be drawn off; and, for this purpose, it is best to use a tub having a false bottom, such as we have already recommended to be used in getting rid of the useless yellow matter.

The liquid so withdrawn should contain all the red matter of the safflower; although, by a second action, similar to the preceding, more may be obtained from the dye-stuff: it is, however, of inferior value to that first extracted.

In respect to cotton, the colour has so much attraction for that fibre, that simple immersion in the liquid thus produced is sufficient to afford an excellent dye. That is, after the cotton goods have been immersed, they must be passed through a solution of citric acid (lemon-juice, or even tartaric acid will answer), to strike the colour; but the two former are much to be preferred. Some years ago we tried the whole range of acids then known; but nothing answers so well as lemon-juice, so far as we could discover. By such means the cotton attains any desired shade of red, varying from pink to the richest and deepest rose; far exceeding, in our opinion, any other colour that can be produced by the dyer's art on that material.

Of course the cotton must be bleached; but the dyer must remember that most cotton goods supplied to him, after bleaching, contain an appreciable quantity of chlorine, which is utterly destructive of the safflower colour; and hence yarn or twist in that condition will greatly increase the cost of rose dyeing by safflower, unless freed from that gas. The best plan to ensure safety in this respect is, first to wash the yarn, twist, &c., in a hot although weak solution of carbonate of soda; then to wash in abundance of cold water; and leave the yarn, &c., exposed to the open air—fine or wet—for a day or two. This opens the fibre, and wonderfully assists the penetration of the dye, and consequently the brilliancy of the colour.

As a rule, the deepest shade of rose is given to cotton by using an equal weight of safflower with that of the material to be dyed; and less deep tints, of course, require a less quantity of the dye-stuff. But no reliable rule can be made in this respect; for the quality of safflower, carbonate of soda, lemon-juice, the purity of water, &c., &c., are, necessarily, liable to constant variation. Quantities, therefore, must be left to the judgment and experience of the practical man.

In a former part of this work, it was stated that, some years ago, we entered into a lengthened series of experiments, in the hope of rendering the beautiful dye afforded by safflower to cotton permanent; but failed in attaining anything like successful results. We attempted, by imitating the celebrated Turkey-red process, to attain that end; used tannin preparations, and various other means; but ended almost where we began. Our success was partially encouraging, for, to a certain extent, we overcame the action of air and light: but soap and alkaline solutions instantly changed the best shades of red to a kind of peach or violet colour; hence, practically, those results were valueless; for all goods dyed of a red or pink colour by safflower, would, necessarily, have to undergo the domestic ordeal of a wash in soap and soda.

Silk is readily dyed by means of safflower; best by the extract usually sold for that purpose, and already mentioned. If, however, that cannot be procured, the colour of the safflower should be first communicated to coarse cotton yarns, in the manner just indicated. It is then to be dissolved therefrom by carbonate of soda, when the red solution, in a concentrated state, will be obtained. Silks have generally communicated to them a slight ground by means of orchil (see *ante*, p. 101). They may be then dipped in the safflower solution, with lemon-juice to strike the colour. Some writers have recommended sulphuric acid; but it is not advisable to use it unless chemically pure—a condition not readily to be found, in regard to that acid, in the dye-house. After removal from the safflower liquid, it is desirable to pass the silk through a solution of tartar in which is some lemon-juice, and then to wash with water. It is important that the water should not contain carbonate of lime (see *ante*, p. 91), because this would seriously affect the brilliancy and permanency of the colour; hence, we believe, arises a very common cause of failure in dyeing from safflower, whether on cotton or silk.

By judicious commingling of dyes, many beautiful colours, besides those of a rose, &c., may be obtained by means of safflower; and in this fact is involved a great amount of science, of much value as a study to the practical man. The nearer a colour approaches to the perfection of nature—by which we mean such as are afforded by the prismatic spectrum, spoken of at p. 86, *ante*—the more complete have we in our hands a means of imitating complex productions of nature in regard to colour. Thus, if the dyer can obtain a *pure* blue, yellow, and red—that is, each of these colours utterly unmixed with any other—he can readily effect—except where chemical causes interfere—a most beautiful result in respect to a compound colour. This may be readily seen in putting two pieces of coloured glass over each other; say a blue over a yellow to produce a green; or a blue over a red to produce a purple; and so on. Now, safflower affords one of these pure colours—the red; hence its careful employment in producing all colours arising from a mixture of red with others, may lead to very excellent results in the dye-house.

It is impossible, however, to suppose that strictly scientific principles can guide all the operations of the dye-house; because, as we have already shown, those who profess to be guides in such matters, must themselves, at times, become learners. Yet science, if it does not at all times give precise practical directions, at least indicates the road to success.

We have chosen first to speak of the most delicate, or, as the French would have it, the most *recherché* production of the dye-house; and we must now descend to materials in respect to the dyer's art, and connected with cotton dyeing, of a much lower degree. For the moment we shall pass by cochineal, lac, &c., to notice dye-stuffs of an entirely vegetable origin. Such, in fact, as leave to the practical man an unlimited, but cheap, choice of producing red dyes, irrespective of permanency. In the trade, such dyes are termed "fancy;" and, as such, are by no means to be esteemed for their permanency. Yet they please; and, so far, they satisfy the cravings of human nature in the way of ornament, if not for "use."

Amongst the lowest class of red dyes, so far as their origin is concerned, we may notice various products of the Leguminous, or Pea-flower order, commonly called, by botanists, the *Leguminosæ*. In regard to the production of dye materials, it is simply prolific. The species number about 7,000; and either as trees, shrubs, or "plants," they are distributed plentifully in every part of the habitable globe. Botanists divide them sectionally, into the *Papilionaceæ*, or butterfly-like winged flowers, including most of those plants that we call "vegetables," in which are included the pea, beans, &c., &c., some species of hemp, clover, indigo (see *ante*, p. 99); gums, soluble in water, being produced by certain species; and red sanders-wood, also a product of one variety. Amongst the *Cæsalpinieæ* are included logwood, which, as our practical readers know, is the heart-wood of a tree growing in Central America; it is a native of Honduras, Campeachy, and generally of the West Indies. It is imported into this country in logs, and afterwards cut into chips, for general and extensive use in the dye-house. Sappan-wood is a source of red colours, the "wood" being imported from Ceylon and Southern India. Cam, or barwood, so largely used as a dye for "Bandanna" handkerchiefs, is, with the preceding, a member of the same order, and subject to the same treatment in the dye-house, that we shall have shortly to describe. There are other woods, as Brazil, &c., that afford reds—all requiring tin as a mordant; but generally they are fugitive.

In respect to logwood, although red in the form of chips, no useful red dye can be extracted from it. The rest that we have named are ranked generically with Brazil-wood—a term applied to many varieties, as is also that of Peach, from Campeachy, where an inferior kind is grown. The whole of them give various shades of crimson and red, generally with chloride of tin; and hence a description of the mode of using one of them is equally applicable to the rest in practice, although the colour-giving power varies. Brazil-wood proper requires alum and tin spirits as its mordants. Camwood affords rich carmine red with tin, and a fine red with alum as a mordant. Barwood, a variety of the same kind of wood, contains a large quantity of colour, with which, however, it parts but slowly, owing to its insolubility.

In all cases these woods are used in chips like logwood; and the advice we have given in respect to preparing a liquor from that wood, at p. 148, *ante*, may be referred to in regard to such as we are now dealing with.

For these dyes, especially barwood, "red spirits" are prepared by dissolving tin in a mixture of about seven parts of strong hydrochloric acid, with one of nitric acid by measure; and such a solution may be used for all these wood-liquors. In dyeing with barwood, the goods or yarn are first immersed in a bath of sumach, to which a little sulphuric acid has been added. About one-third of the weight of the goods indicates the proportion of sumach to be employed. After draining they are worked through some red spirits, of a strength about 3° Twaddell (see *ante*, p. 130). Meanwhile, a hot bath of barwood is prepared, one pound of the wood being used for each pound of cloth or yarn. After the latter have been worked in the spirits until they assume a light yellow, they are well washed, and then transferred to the barwood liquor, which should be nearly boiling; and here they are wrought until the desired red is produced on them. The quantities of all materials here named must be considered as approximative only, for each dyer varies in the proportions he prefers; and, as we have already seen, there is abundance of license generally permissible in such matters. Wool and silk readily take colour from all the woods we have named, but cotton, with this, as in all other colours, requires more trouble. For all shades of red, it is better used in the bleached state, and care must be

taken to free it from all traces of chlorine, which would certainly injure the tint that could be communicated by any of the red woods named.

The use of madder as a dye-stuff for red dyeing, or its extract, garancine, is most especially connected with what is familiarly known as the Turkey-red dye, one of the most intricate and difficult operations found in the art of dyeing. It will be unnecessary for us to give more than a general outline of the process; because the production of this dye is a matter of special processes, in which none but large establishments engage in; and such have, or adopt, certain modifications of the "established" process, that render minute details, to be truthful, impossible.

The great point that the dyer of Turkey-red aims at is, to induce on cotton goods (to which alone we here direct attention) a similar affinity for colouring matter—either derived from madder or garancine, its extract, made by the action of sulphuric acid (see *ante*, p. 101)—equal to that which animal matter exercises, such as we find in wool and silk. The first step in this process is to remove all matter that can possibly exert a preventive influence in the attachment or affixing of the dye. It is, therefore, necessary to remove the resinous matter that we have so frequently alluded to as hindering the communication of colours from dye-stuffs. This is effected by steeping in a strong alkaline ley, as of soda, potash, or lime. In regard to calico, the dressing—that is, the starch—must be entirely removed.

After some time steeping in the alkaline solution, abundant washing in water must follow, so as to remove all substances that could possibly exert a prejudicial influence in respect to future processes. The dash-wheel should therefore be had recourse to (see *ante*, p. 126). Subsequently, the water is driven out of the yarn or goods, either by the water-extractor, or by a Bramah's press. Soap, dissolved in hot water, becomes the next liquid into which the material is passed, followed by washing and drying. So far as we are able to judge of this peculiar and complex process, such operations have the effect of opening out the pores of the goods, and making them susceptible of what we may term the dye influence; but the theory of Turkey-red dyeing is far from being popularly understood. It is next necessary to impart fatty matter to the goods, which is usually done by dipping them into a mixture of soap and oil; and we are not quite sure as to whether the science of this part of the process is, as yet, fully understood. Suffice it to say, that the next step is to expose the yarn or goods to the action of the air; and doubtless this has, to a certain extent, the effect of converting a portion of the oily matter into a kind of resinous substance, by simple oxidation. At all events, so great a change is produced on the cotton fibre, as to make it, eventually, susceptible of the madder colour in a permanent form. We must, however, bear in mind, that the subsequent immersion in a bath of sumach and alum, adds to, and, perhaps, perfects, the quasi-animalisation of the fibre. With a certain repetitive performance of these preliminary processes, the bath of madder, or rather of garancine (see *ante*, p. 101), is had recourse to occasionally, but, so far as we can see, not necessarily, with the addition of bullock's blood (see, respecting albumen, *ante*, p. 121). An alkaline bath, washing, and immersion in a dilute solution of chloride of lime, doubtless, to afford an ozonic effect (if we may coin a new phrase), followed by abundant washing, concludes this intricate process.

So far we have described what we may call the outlines of the standard process of Turkey-red dyeing as regards cotton. We do not feel called upon to explain the variations to which such a process may be subjected, simply because such variations are generally the result of special views entertained by those whose experience entitles them to a great amount of respect.

If any of our readers feel inclined to attempt to carry out this process, having been unaccustomed to its details and peculiarities, we can only say that any precise instruction on our part would by no means help them. They would have to acquire knowledge by experiment only. Independently of this, we must add that our work is not intended for those who are fully acquainted with all dyeing processes, but rather to teach those principles that the practical man is frequently ignorant of. We wish to raise the standard of science amongst our working friends in the dye-house.

Cochineal is a rich source of red, or rather crimson, with a tin mordant and alum. In respect to directions for its use, we feel much hesitation in committing ourselves, so various have been the proportions that have been recommended. Tartar seems, at times, essential, perhaps simply from its acid character, to effect a really good colour. Lac is, to a certain extent, similarly used to cochineal. In any case, galling—that is, an immersion in some astringent—is occasionally desirable. With a bath of cochineal, tartar, red spirits (see *ante*, p. 154), and alum, almost any shade of deep red to pink may be produced on wool. But the use of cochineal and lac is so much identified with long practice in the art of dyeing, as to render it unnecessary for us to give special directions in respect to them. As a rule, the instructions given regarding red wood dyes are, more or less, applicable to all operations connected with the production of rich red colours. We have preferred to devote most attention to those sources of red colours that are less known, and more difficult of practice. Various shades of purple, peach, lilac, lavender, &c., are obtained by a judicious use of logwood and tin solution, in the form of what is called a plumb-tub; although many of the dyes so obtained are now derived from aniline colours, to be hereafter described. A protochloride of tin is produced by dissolving that metal in muriatic (hydrochloric) acid, which should be done gently, by adding the tin in small quantities at intervals, so as to keep down too rapid action. A decoction of logwood is then made in the usual manner; and it should have a strength equal to about 8° of Twaddell. After

being allowed to stand for some time, so that all flocculent and other matter is precipitated, and kept cold, the protochloride just named is added, until the liquor attains 14° of gravity, according to Twaddell. This liquor is one of considerable value to the dyer ; for, being once prepared properly, it keeps for a long time, and is invaluable, in the absence of certain aniline dyes, for a great variety of purposes. It does not, necessarily, require a mordant ; and if this be used, the colour of the "plumb" employed is communicated to the goods. The amount of this seems to depend on the strength of the liquor thus made. In respect to its chemical constitution, we may quote the words of a writer to whom we have been already indebted for many valuable hints, at least so far as regards the methods of dyeing by mordants and vegetable colours. He says—

"We cannot help inquiring here upon what theoretical law does the dyeing by the plumb-tub depend ? It is not ordinary precipitation ; for this compound is soluble, and is held in solution for years ; we have known one kept (for) two years and a-half, and used after (that period). The goods (need) have no mordant upon them previously to being immersed (in the plumb-tub) ; and in a short time they obtain a dye sufficiently permanent to stand all the usual 'fatigues' of fancy colours. That it is a chemical union between the compound constituting the plumb-tub, and the cloth, is not tenable ; for * * * this cannot take place but between the atoms of matter, and at the expense of the original properties of the two substances that combine. Now, the cloth remains unchanged in properties, except colour, which may be taken off (from it) without in the least interfering with the properties of the cloth. Our opinion is, that in this, as in several other cases in dyeing, the cloth exerts a catalytic influence over (on) the compound of tin and logwood ; that is, a certain power of causing bodies in contact to combine or resolve themselves into other compounds, while the substance exerting the influence is not affected—as, for instance, a piece of platinum put into a mixture of oxygen and hydrogen gases, to combine and form water ; or a little sulphuric acid put into starch, will convert the starch into sugar, without the acid being destroyed.* So, in the same way, the cloth being put into this *soluble* solution of tin and logwood, may, by inducing a very slight transformation, convert it into the *insoluble* compound of tin and logwood, and, like other dyes, fill up the hollow fibres of the cloth, &c., producing dark or light shades accordingly."

The great value of this "tub" consists in the variety of purposes to which it may be applied ; for, as we have already stated, almost every variety of shade, from a light gray to a plum colour, may be obtained by its use ; a judicious exercise being made of its colouring properties, for which, of course, some experience in dyeing is necessary. A preparatory "galling," by means of sumach, is frequently desirable, so as to not only give a permanency to the colour, but assist it in the deposition on the yarn or goods.

By means of safflower, as we have already stated at p. 154, *ante*, and either the blue vat or Prussian blue, a great variety of colours, varying from lavender to purple, may be obtained ; the scientific principle involved being the super-position of red and blue, or *vice versâ*, on the fabric. Similarly, most shades of brown may be produced by a judicious union of red with yellow. Almost any yellow vegetable stuff may be first employed ; and on this, with an alum mordant, a decoction of one of the red dye-woods already mentioned at p. 154, *ante*, with an alum mordant, will afford the requisite shade. Catechu and aloes are used in brown dyeing ; the former preceding a subsequent immersion in a solution of bichromate of potash. The use of prussiate of potash, with a copper salt, has been already described at p. 117, *ante*.

In dyeing purple generally, a rule lies, that the use of sumach with "red spirits" tends to produce a brown, and that of logwood a blue tint, just as either of these have the predominance. Thus, with a spirit yellow—that is, for example, a yellow produced by spirits of tin and quercitron, followed by a bath of logwood—many shades of brown may be produced. These may be raised by a little red liquor or spirits.

So far our remarks in dyeing various shades of red, &c., have mostly related either to silk or cotton ; but especially the latter. Wool receives an excellent red from sappan-wood, with a tin mordant ; or by first immersing it in a solution of bichromate of potass and alum, and subsequent working in a bath of Brazil-wood. Crimson is communicated by means of a bath of cochineal, with tin spirits and tartar ; and various shades of pink may also be produced from the use of the last-named agents. Sheep's wool, in its raw or manufactured state, is in a kind of intermediate condition between silk and cotton, having the readiness of receiving dye like silk, but being a little higher in price than cotton ; hence, in the dye-house, a kind of shifting, if we may so call it, or, more properly, an oscillation, may be made between the use of the dye-stuffs, commonly the sources of cotton and silk dyes, for similar colours.

The use of orchil and other lichen dyes is chiefly confined to silk, especially in producing what is called a French or pearl-white, in which tints of red and blue produce a colour somewhat approaching a gray. Of course, such are very fugitive. As usually extracted by ammonia (see *ante*, p. 98), these dyes have a blue colour, instantly turned red by an acid ; hence even the atmosphere itself is capable of causing a change in the tint. At the same time, the latter is very delicate, and generally has been much patronised by the fair sex, for whom dyeing operations, as a rule, are chiefly carried on.

It is impossible, in our limited space, to notice all the varieties of colour that may arise by a combination of red with blue and yellow, forming the varieties of purple and browns ; and which

* This is barely true ; because it requires long boiling to convert starch into grape sugar by means of sulphuric acid. We note this to the general reader, for the scientific man will at once understand what is here meant, and will make all allowance for ellipsis in description.

have received so great a variety of names. They all arise from mixtures, in various proportions, of the primary colours; and it is impossible to accurately define the processes by which they may be produced. We have pointed out, however, those general principles that should guide the practical man in his attempts to produce them; and having gone so far, believe that our duty ends; for to profess to give instruction where no real and truthful basis lies, is rather to hinder than aid.

Of late years, the tendency of improvements in dyeing has been towards the substitution of "extracts," "principles," &c.; that is, those essential matters of dye-stuffs on which their colouring properties depend. In respect to madder, for example, garancine, alizarine, purpurine, &c., have been, to a certain extent, substituted for the powdered root, as we have already intimated in an earlier portion of this work. Speaking of these improvements in the use of madder, and its derivatives, the late Dr. Crace Calvert, one of our most eminent authorities in such matters, remarks—"Our chemical knowledge of the composition of this root, was, up to 1851, in a most unsatisfactory state. Thus, whilst we find that MM. Decaisne, Jean Gerber, Edmund Dollfus, &c., asserted only one colouring principle, to which they gave the names of *alizarine*, *colorine*, or *azale;* others, such as MM. Persoz, Runge, and others, admitted two colouring principles—*alizarine* and *purpurine;* and Kuhlmann added to these a third, called *xanthine*. But Dr. Edward Schunck, F.R.S., published, in 1851, his most valuable and extensive researches on the chemical composition of madder, which not only threw much light on the colour-giving principle of the * * * root, but also led * * * to valuable commercial applications."

At p. 101, *ante*, we have already directed attention to the uses of *garancine*, *alizarine*, and *purpurine*, as products of madder. Very recently, however, and by a peculiar process (to which we shall afterwards have to allude, in connection with calico-printing), these principles have been largely brought into use, and with the best effects, in producing a considerable variety of lilac shades. Numerous valuable processes have arisen from a careful treatment of garancine, or the extract of madder. On this subject we may quote again the words of Dr. Calvert, who very kindly has placed in our hands his *Lectures on Coal-tar Colours, and on recent Improvements, &c., in Dyeing and Calico-printing.* He observes—"Messrs. Schaaff and Lauth having exhibited, in the French department of the late Exhibition (1862, held in London), some most beautiful commercial preparations obtained from madder, called by them *Purpurine*, and *Green Alizarine*, I forwarded samples to Professor Stokes, who pronounced the alizarine to be composed almost entirely of that substance, with a dark green resin, which Emile Koff considers to be produced by the decomposition of chlorogenine; whilst the *purpurine* was declared by him to be that substance in a high degree of purity. As both these substances are now beginning to be extensively used by French printers, and, to some extent, by English houses, I cannot do better than give an outline of Messrs. Schaaff and Lauth's process, as devised by the eminent chemist, M. Emile Koff. Six hundred pounds of ground madder are allowed to macerate for ten hours, in a vat containing 800 to 1,000 gallons of a solution of sulphurous acid (*sic*); and, after running off this liquor, the madder is again treated with 200 to 250 gallons of the same acid solution. These liquors are then mixed with 3 per cent. of sulphuric acid, specific gravity 1·60; and the whole heated to about 100° by means of steam, when the purpurine separates itself under the form of large flakes, which, in a few hours, settle at the bottom of the vat. The liquors are then run off, and carried to ebullition for three or four hours, when a new substance, called *green alizarine*, is liberated, and precipitates. Both these products require only washing to be ready for the printer. The dyeing power of these new substances is remarkable; that of purpurine being equal to forty or fifty times the same quantity of madder. * * * The 600 pounds of madder yield about four pounds of *purpurine*, and about sixteen of *alizarine*. The latter can be employed for the same purpose as the commercial alizarine; whilst the 'purpurine' gives magnificent reds and pinks with alumina mordants, but no purple with iron mordants—doubtless from the absence of tannin matter. Wool mordanted with alum and cream of tartar, or a solution of tin and tartar, takes the dye well." Dr. Calvert states, that the solution of tin should be prepared by mixing thirty parts of nitric acid, ten of water, and five of sal-ammoniac, to which fifty parts of tin are gradually added; and the temperature of the liquid is to be kept at the lowest ordinary degree. It requires some days before this mordant is ready for use; and then the wool is dipped in a bath, at about 80°, containing a small quantity of the above solution; and the bath is raised, during half-an-hour, to about 186° temperature. The wool is then removed, and washed. It is then dyed with purpurine, in a bath containing the colouring matter; the temperature of the bath commencing at 86°, and rising to the boil in half-an-hour.

According to the same authority, purpurine, neutralised by carbonate of soda, is capable of affording a brilliant crimson to wool mordanted with alum and tartar; and a rich scarlet, if it be mordanted with tartar and a solution of tin, almost equal to that obtained from cochineal; and by means of fustic, a rich orange-red may be obtained, tartar and tin being used as mordants, and the purpurine bath following the fustic.

We may here notice a splendid silk dye of a deep purple, obtainable from orchil, and called French purple. This is prepared by treating lichen substances (already described at p. 98) with milk of lime, by which the colouring principle is held in solution. It is then precipitated by hydrochloric acid; and the precipitate, after washing, is dissolved in liquid ammonia. The

solution is kept at a temperature of about 160° for about three weeks, when the colour principle, with the ammonia and oxygen, are transformed into new products, in the form of purple-coloured lake, precipitable by chloride of calcium, salts of alumina, tin, &c. This product affords rich dyes of purple, mauve, &c., either alone, or by the addition of indigo, and some coal-tar dyes, as roseine, &c. ; and such colours are distinguished from those ordinarily produced from orchil, by being permanent in respect to the action of light. Oxalic acid is used as a solvent of this lake ; filtration is used ; and the clear solution is employed as a bath. Cotton, mordanted with albuminous matter (see *ante*, p. 121), wool, and silk, readily take the colour, which is exceedingly rich as a purple or mauve. Artificial alizarine is now largely prepared from naphthaline, a product of coal distillation, and is much used in dyeing reds.

Guano has, from its containing uric acid, become a source of red colours, or rather those more inclining to purple. In an earlier part of this work, we have alluded to the fact, that urine contains a colouring matter, to which the name of *murexide* has been given. By means of the action of hydrochloric acid, for the removal of soluble matters in that menstruum, on guano ; then of nitric acid ; washing, &c., this dye-substance is extracted, which is now used for calico-printing, and other similar processes, where red and purple colours are required. The murexide so obtained, being treated by the perchloride of mercury, acetic acid, and acetate of soda, according to the tint of colour—red or purple—that is required, affords the last-mentioned colours.

We thus find how numerous are the sources of colour that may be employed in the dye-house ; and are glad to see the day when scientific principles are gradually gaining the ascendancy over empiricism. At an early part of this article, we complained of the uncertainty with which dyeing operations are attended ; but, at the same time, made full allowance for this fact, in the peculiarities that attend the production, preparation, and use of dye-stuffs. During the interval of from 1856 to the present day, many additions have been made to our sources of colours, even apart from the discovery of aniline dyes, that date from about the same period. Much of these results is due to an application of the doctrine of substitutions, that, to understand, would require a considerable amount of chemical knowledge on the part of our readers, and which we therefore forbear entering into the discussion of. Suffice it to say, that, in our time, valuable discoveries arise less from chance, and more from sound philosophic induction, than they have ever yet done ; hence their adaptation is much more rapidly effected, and the results thereby obtained are more perfect in character than could otherwise have happened.

We cannot, of course, foretel what changes may speedily occur in the practice of the art ; but one thing is certain ; and that is, its processes are constantly becoming more simplified ; and with this simplification, a greater and more popular use results. In the early days of photography, few, indeed, were those in number that practised it, because its processes were so intricate, and devoid, to a great extent, of scientific precision, either in direction or result, that even the man of science found it barely possible to attain to anything like proficiency in its practice. But no sooner did the processes become more simplified and exact in their nature, than a host of "photographers" sprang up from every branch or class of society. The spirit of emulation was excited ; and, without going through a lengthened detail of the various steps by which the art has passed, until it has arrived at its present perfection, we may observe, that the number, rather than the special ability, of its followers has fostered its maturity. So, possibly, in dyeing, as the means of producing the varied tints of colour become more extendedly understood and practised, the art will become more fully known ; the conditions essential to its successful practice will be better understood ; greater requirements on the exertions of the dyer, in the production of permanent and brilliant colours, will arise ; and thus, step by step, we may expect this application of chemistry—so exceedingly adapted to please the taste of the most refined, whilst it fosters the pride of ignorance—so highly suggestive of beauty, because it copies nature's perfections, although it falls short of them—will, through patient perseverance, be made to take a position like the sister arts of painting, drawing, and engraving, and become a means of expanding education in its most refined, because æsthetic tendencies.

We now turn to a description of the practical uses of aniline or coal-tar dyes.

Practical Use of Coal-Tar Colours.

At a former page (122, *et seq.*), we gave a general outline of the sources, production, and characters of some of the aniline or coal-tar dyes, that are now so rapidly being substituted for others, of vegetable and mineral origin, of which we have just concluded the description. We will now turn to consider certain points in their production and use, that will be of practical value in the dye-house.

It is to Faraday that we are indebted for the first isolation of benzine, or benzole, from the products of coal distillation, which he effected in 1825. Dr. Hofmann subsequently produced aniline from coal-tar ; and thus laid the foundation of the valuable discoveries in respect to these dyes. The first patent that was taken out was in 1856, by Mr. Perkin, a pupil of Dr. Hofmann.

Purples.—Perkin's purple was the first aniline colour produced and used for dyeing purposes. That gentleman employs equivalent proportions of sulphate of aniline and bichromate of potass (the latter as an oxidating agent). When the solutions of these salts are mixed together, decomposition takes place, and the sulphuric acid of the sulphate of aniline passes to the potash to make a sulphate of that alkali. The solid residue is filtered, washed with water, and dried.

It is subsequently digested with coal-tar naphtha, to free it from all resinous matter. The result is dissolved in spirits of wine, to which it imparts its characteristic colour. This aniline purple is barely soluble in cold, but more so in hot water, from which it separates, on cooling, as a purple jelly. It is soluble in strong sulphuric acid, to which it gives a green appearance; instantly becoming of a rich blue on dilution with water. In many respects it resembles indigo, in relation to its chemical characters.

Subsequently other patents were taken out for producing purple from aniline. The results, in each case, are similar; the aniline being nearly alike in its dyeing properties, and imparting them to wool and silk by simple working in its solution; and to cotton, after tannin from sumach has been imparted to the fibre.

Reds.—Rosaniline, also known as Magenta—a rich red, which has always been very popular since its discovery, especially as a dye for silk—may be prepared by heating one part of bichloride of carbon with three of aniline, to a temperature of 350°, in a close vessel. It is soluble in alcohol. By another process, anhydrous bichloride of tin is substituted for the carbon; and a heat of nearly 400° is required to effect decomposition. A dark-red liquid is produced, which, after being cooled, is mixed with boiling water, and filtered; common salt is then added, when *Fuchsine* (another name for the Magenta) is precipitated. Its solvent is spirits of wine, or—what is much cheaper, and is used generally to dissolve the aniline dyes—methylated spirits. Other methods of producing Magenta have been patented, that we need not here describe. Silk and wool readily take this dye by simple immersion in an acidulated solution of it. Cotton requires the preparation already alluded to. Roseine, azaleine, and fuchsine are all varieties of Magenta; being, respectively, the acetate, nitrate, and hydrochlorate of rosaniline.

The two preceding series of colours, purples and reds, far exceed in beauty anything that can be derived directly from any vegetable product; and, as we have noticed, when properly dissolved, require no art whatever in their use for dyeing purposes, except as regards cotton, which must have communicated to it tannin matter, in a way we shall subsequently notice, to fix these dyes. The depth of colour becomes simply a question of quantity and time, as no mordants are required for them or any other of the coal-tar dyes.

Blues.—In respect to the blue colouring matter, from aniline, the late Dr. Calvert, in an exhaustive work on the subject* (to which, as also to the author, we are indebted for most valuable information in respect to these dyes), classifies the aniline blues under three different heads: viz.—

"1. Blue colouring matters of light hue, resisting the action of acids, and, to a certain extent, that of light, but decolourised by alkalies. Such are called *Azuline*, prepared by Messrs. Guinon, Marnas, and Bonnet, of Lyons; that prepared under Mr. C. A. Girard's patent, and called *Bleu de Lyon;* also *Bleu de Paris,* prepared by the process of Messrs. Persoz, De Luynes, and Salvétat; and, probably, the *Bleu de Mulhouse*, obtained by the process of Messrs. Gros-Renaud and Schæffer.

"2. Blue colouring matters giving shades very similar to those of indigo, offering great resistance to light and alkalies, but turned green by acids. Of this kind are *Azurine*, patented by Messrs. Crace Calvert, Clift, and Lowe; and the same colouring matter as observed by M. Fritzche, M. Emile Koff, &c.

"3. Blue colouring matters of a light shade, but highly fugitive, turning yellow when in contact with acids; such as that produced by Mr. Lauth's method."

All these sources of aniline blues are the subject of patents; and hence it will be unnecessary, in a practical work like the present, to enter into a lengthened description of these productions; which, indeed, would require considerable knowledge of chemistry for our readers to understand. To dye silk or wool blue, Dr. Calvert instructs thus:—"To an acidulated lukewarm bath of water, an alcoholic (spirit) solution of azuline is added, and the silk or wool worked in it until it is of the required shade. It is then transferred to another bath of boiling water, acidulated with sulphuric acid, when the purple colour is dissolved, leaving a most brilliant and permanent blue upon the material. The dyed silk or wool is washed repeatedly, passed through a bath containing a little tartaric acid, and dried."

In respect to dyeing cotton all the precedingly described colours—which, as we have stated, are at once taken by silk and wool without any preparation beyond that of scouring and cleansing from gummy matter—the processes are preceded by soaking the yarn in a decoction of sumach, or other astringent matter, for an hour or two. The yarn is then passed into a weak solution of stannate of soda (a compound of peroxide of tin and soda): and, after having been worked therein for an hour, it is wrung out, dipped into dilute sulphuric acid, and well rinsed. To dye the cotton so prepared, it is simply necessary to work it in a slightly acidulated bath containing aniline purple or Magenta.

Carbolic acid, so largely used for disinfecting purposes, and a product of coal-tar, affords a blue dye identical with azuline, already noticed; and a rich red called *Peonine*, derived from rosalic acid: the latter has been recently introduced into the dye-house as a source of red colours.

Yellows.—The source of coal-tar yellows is picric acid, which is readily obtainable by the action of strong nitric acid on a considerable variety of substances, as silk, indigo, &c., &c.; but, for commercial purposes, carbolic acid is that adopted. When the carbolic and nitric acids are mixed together, a powerful action ensues; and, after a time, yellow crystals are deposited, that consist of picric acid. This has enormous colouring properties. M. Emile Koff states, that one

* *Lectures on Coal-Tar Colours, &c.;* by Dr. Crace Calvert, F.R.S., Professor of Chemistry at the Royal Institution, Manchester, &c., &c.

part of picric acid, dissolved in water, with a little sulphuric acid, is sufficient to give, to 1,000 times its weight of silk, a moderate shade of yellow. Wool requires first mordanting in a little cream of tartar and alum, to render the colour fast; but a good yellow may be procured by simple immersion in, and working in, the above-named solution.

Greens.—These colours may be afforded, of various shades, by the use of picric acid and indigo, or Prussian blue. The directions given for dyeing greens, at p. 145, *ante*, may be adopted, picric acid being substituted for the sources of the yellow there named.

Besides the various colours here described as resulting from treatment of aniline, &c., there are some that have come into use from other coal products. Naphthaline has thus been utilised by Mr. Perkin, and others; but as no information of a practical nature, differing from that already given as to the use of aniline dyes, is needed, we shall not enter into the subject. Picric acid, by the action of cyanide of potassium, produces a red dye, the isopurpuric acid, similar to murexide, described at p. 158, *ante*. Indeed, now our knowledge of the doctrine of substitution in organic chemistry is so extended, both theoretically and practically, there seems hardly a limit to the number of products we may hope to obtain for dyeing, and other economic purposes. But a few years ago, coal-tar was only valuable for preserving wood-palings, or ships' bottoms; and was worth but a few pence per gallon. Now, it is literally a mine of gold. This result has arisen solely through the application of scientific experiments and induction, carefully built on previously known facts, which, as they have been extended in number, have produced applications of the highest value in commercial and social life generally. So far as British dyers are concerned, the discovery of coal-tar dyes has been of the utmost importance. Formerly, when our only sources of colour were those of a vegetable origin, we were far behind the French, in respect to brilliancy, if not permanency. From whatever cause this arose—and, to some extent, we have discussed the question in an earlier part of this work—we were certainly inferior, then, to our neighbours across the Channel in our dye productions. But the coal dyes have placed us on a level; and we are now enabled to equal, in all respects, the productions of foreign origin. As we shall subsequently find, a similar result has arisen in respect to calico-printing.

With these observations we conclude the first subject of this chapter; and proceed to describe the present methods adopted in bleaching cotton goods of all kinds. The latter subject will be followed by an account of the methods of calico-printing, from which, we believe, those of our readers who merely pursue dyeing operations may acquire many useful hints: for, although calico-printing and dyeing are precisely similar operations, so far as their scientific principles are concerned, the details of the former processes vary greatly from those of dyeing in their mechanical and chemical details.

BLEACHING.

The art of whitening all kinds of textile fabrics, is one, like that of dyeing, of ancient origin; and is equally, and was so, dependent on the aid of chemistry. But, certainly, we must give more credit to the bleacher, in availing himself of this science in improving his processes, than we can possibly do for the dyer. We have already intimated that, to a large extent, dyeing is an empirical art; often barely dependent on principle in respect to its practice, and still less characterised by precision. Not so with bleaching. Every step should be organised and dictated by strictly scientific rules, because they aid directly the speed and certainty of the process. The system of cotton bleaching carried on before the discovery of the use of chlorine, was one exceedingly tedious, uncertain (we should fancy, unprofitable), and dependent, like the making of hay, on sunshine. Barlow thus describes it:—

"The first operation in the old system, as in the new, is to remove a substance termed sowens [he refers to woven goods], which is a paste made of flour and water, used during the weaving, for the purpose of closing down the fibres of the thread, and thus allowing them to pass more freely through the reed and harness (of the loom). This consisted in steeping the goods in a vessel of lukewarm water, till a gentle fermentation took place, which usually required about twenty-four hours. The cloth was then taken out, and well washed in a current, which removed a considerable quantity of the filth without the use of alkaline leys.

"The goods were then boiled in a vessel containing a solution of potash (pearlash), and furnished with a winch and rollers, by which the cloth could be moved about in the liquor, and by that means be thoroughly impregnated with it. This was continued as long as the liquor appeared to abstract any colouring matter from the cloth, which was then taken out, and well washed in water. The use of this process depends upon the properties which alkaline salts (substances, not salts) possess of uniting with the oily and resinous matters which are either attached to, or are a constituent part of the vegetable fibre.

"The next operation is termed *bucking*, and is similar in principle to the last, although a more powerful application of it. The goods are placed in a vessel called the 'bucking-tub,' and a powerful solution of the alkaline ley is poured upon them from a vessel, where a quantity is kept constantly boiling. When the goods are thoroughly impregnated with the boiling ley, it is allowed to pass off into an iron vessel, whence it is pumped back again to the boiler, and returned hot again upon the cloth; which process is continued for some time. The cloth is then taken out, well washed from impurities, and laid upon the ground, to be whitened by exposure to the atmosphere.

"In order to dissolve and remove any metallic or earthy (mineral) matter, inherent in the

cloth, or which may have been derived from the impurity of the alkaline solutions, an operation termed souring is employed. The goods are immersed, for about the space of twelve hours, in a mixture of sulphuric acid and water, well incorporated, the proper strength of which should be about (equal to) the acidity of lemon-juice; and was usually determined by the taste. The goods may be put into this acid (solution), either in a wet or dry state; but the best plan is to immerse them in the evening in the acid liquor, cold; to let them remain covered with it all night; then in the morning to make a fire, and bring the liquor to a blood-heat, in which state the goods should have a few turns, in order that every part of them may be equally exposed to the fluid. The goods are then wrapped round the winch to strain them a little, to prevent an unnecessary waste of acid, and afterwards carried to the wash-wheel or river, to be washed till there is no acid perceptible to the tongue, remaining in the cloth or (yarns). It is a remarkable circumstance, that cloth may remain immersed (for) a considerable time in strong acid liquor without rotting; but that if exposed to the air, or the heat of a stove, if a very small portion of the acid remains on the cloth, it becomes so concentrated by heat as to damage the material immediately; too much attention cannot, therefore, be paid to this point. [See our remarks on this subject, at p. 110, *ante.*]

"The operation of bucking was repeated for some cloths a great many times, each time requiring, with the subsequent operations of leying and watering in the bleach-field, the period of a week. The first two buckings were with very strong ley, which it was (subsequently) necessary to diminish in strength, to prevent injury to the cloth.

"These operations could be carried on only during the summer months; and during four months in the year, bleaching by the old system was entirely suspended, and the capital of the manufacturers or proprietors of the goods (was) locked up, and useless: the immense time (during) which the goods were under operation, was also the means of a great consumption of capital. Cotton goods which required from four to six applications of alkaline leys, consumed as many weeks in bleaching; while linens, which could not be bleached by less than from twelve to twenty applications, could scarcely be brought into a marketable state in less than six months."

Such is a general outline of the old method of bleaching, which, although abolished for several years, is yet well remembered by many of those who had formerly to suffer for its uncertainty, and lengthened operations. Chemistry at last presented us with a method, by which we can now effect a far better result in as many *hours* as it formerly took *weeks* to accomplish—nay, we we might say almost months.

Thanks to Scheele, the celebrated Swedish chemist, the discovery of chlorine placed in the hands of the bleacher an agent far superior, in its effects, to that of simple exposure to air, light, and moisture, on which the whole system of bleaching chiefly depended. It is not certain, however, as to whom we are indebted for the first application of this element, for practical purposes, in regard to bleaching. It is stated by Barlow, that Scheele wrote to our countryman, Kirwan, informing him of his discovery of chlorine, and this special application of its bleaching powers; that Mr. Kirwan mentioned the subject to Mr. Taylor, then secretary to the Society of Arts, and this independent of any knowledge that the celebrated chemist, Berthollet, had of the process, and to whom some ascribe its discovery. Concluding the narrative of this statement, it is added, that, in 1788, a whole piece of calico, in the state received from the loom, was bleached, printed in permanent colours, and produced in the market at Manchester for sale; having undergone all these processes in less than forty-eight hours. According to the same authority, however, it would seem that we are much indebted for the early progress of bleaching by chlorine to Berthollet, whose exertions in carrying out the application of chemistry to dyeing, &c., have been of such great value to the practical man.

At first, mere immersion in an aqueous solution of chlorine was adopted; but this method is both uncertain and wasteful, for the chlorine soon decomposes the water, to form hydrochloric acid with its hydrogen; and not only so, the watery or aqueous solution is generally too weak to be of any practical value. Next, therefore, to the discovery of chlorine by Scheele, we are indebted to Mr. Tennant, of Glasgow, who was the first (*cir.* 1798) to introduce the use of chloride of lime, or bleaching powder, in which the chlorine is weakly combined with lime; and in that condition is of the highest service to the bleacher. His descendants still carry on business near that city, and rank amongst the most extensive and prosperous chemical manufacturers in the world at the present day.

Whilst, however, our modern method of bleaching so greatly differs from that previously adopted, it is by no means certain that the actual chemical processes differ. Dry chlorine—that is, the gas perfectly free from moisture—has no power whatever in abstracting the colour of vegetable bodies; and there is no doubt but that at least the presence of one constituent of water is absolutely essential to our modern methods of whitening or bleaching cotton fabrics.

The chief source, and, indeed, the only commercial one, of chlorine, is common salt, which chemists view as a combination of that element and the metal called *sodium;* hence our table salt is denominated, in the laboratory, *chloride of sodium.* By adding sulphuric acid to this, a compound of chlorine and hydrogen is given off, familiarly known as spirits of salts, or muriatic acid; but now universally called, in accordance with our chemical nomenclature, *hydrochloric acid.* If this acid be heated with the black oxide of manganese, or—what is equivalent thereto—if common salt, sulphuric acid, and the black oxide of manganese be all heated together in a proper vessel, chlorine gas—so called from its

yellowish-green colour—is given of. In preparing the bleaching powder, this gas is absorbed by lime, over which it is allowed to pass, until what we usually call saturation is effected; that is, the lime takes up all the chlorine that it can possibly combine with.

What the precise effect of chlorine is in bleaching cotton or linen goods, is not known. It will be our business, presently, to enter into all details of the process of bleaching; but, for the present, we may observe that it is necessary first to remove certain extraneous matters incidental to such goods, by means of alkaline leys, before chlorine can properly exercise its bleaching effects.

It does not seem, as far as chemical analysis has yet shown us, that bleached cotton differs essentially, or, perhaps, we should rather say, constitutionally, from that in the raw state. And, thus far, the results of bleaching are different from those that arise from the action of nitric acid on cotton, as seen in the conversion of this material into what is familiarly known as *gun-cotton*, now much used for blasting purposes. In any case, we find that the removal of colouring matter is effected, chlorine having great power in destroying such forms of vegetable matter.

If the chlorine is presented in a highly concentrated condition, however, the destruction of the fibre is sure to ensue; hence, in bleaching operations, it is of the utmost importance to regulate the strength of the solution of chloride of lime employed; and to prevent—what very often happens—the contact of solid pieces of that substance with the goods under process of bleaching. In respect to yarn this point is of even still greater consequence; because if the tenacity of a portion of the fibre be destroyed, a whole hank may become valueless. A branch of chemical analysis is, therefore, necessarily of frequent practice in the bleach-house. It has received the name of *chlorimetry*, or *chlorometry;* and has for its object to ascertain the strength of chloride of lime solutions employed for bleaching purposes.

An able and excellent paper, written by a personal friend, who stood pre-eminently amongst practical chemists, and still more so in his commercial relations in respect to bleaching, dyeing, and calico-printing—the late Mr. Walter Crum, of Glasgow—will put our readers in possession of much historical and practical knowledge of this subject. We shall not hesitate to quote freely from it, because his name is a tower of strength, and himself an authority of more than forty years' standing in such questions. After remarking that the commercial value of chloride of lime cannot be judged of by external characteristics, but only by chemical tests, he briefly describes some of the methods that have been adopted during the last forty years. The earliest plan was that of making a solution of indigo the test, by its decolourisation, of the quantity of free chlorine present. It was found, however, that, despite all the care used in preparing the test solutions, uniform and reliable results could not be always attained; and hence the indigo method was not to be relied on, as a veritable guide, in estimating the commercial value of any liquid in respect to its chlorine present. Another plan was that of converting the subchloride of mercury or calomel into corrosive sublimate, by causing all free chlorine to combine with the calomel, and thus convert it into the soluble salt, containing a greater proportion of chlorine. In 1835, the preceding methods having been more or less followed from 1824 to that year, Gay Lussac, the celebrated French chemist, proposed the use of arsenious acid, or white arsenic, as it is sold in the shops by that name; which, by its union with all free chlorine in any solution, becomes a test for the presence of that agent. The test solution of the arsenic acid was such as to be just sufficient to take up an equal volume of chlorine in its saturated solution in water. Numerous other methods have been proposed; but a very simple one, described by Mr. Crum as one in constant use, is as follows; the description being given in his own words:—

"Chlorimetry requires to be practised by the bleacher for two purposes. First, he has to learn the commercial value of the bleaching powder which he purchases; and with that view he can scarcely desire anything better than the method either by arsenious acid or green copperas (both of which we will presently describe). But the more important, because the hourly testing of his bleaching liquor, and that on which the safety of his goods depends, is the ascertaining the strength of the weak solutions in which the goods have to be immersed. If the solution is too strong, the fabric is apt to be injured; if too weak, parts of the goods remain brown; and the operation must be repeated. The range within which cotton is safe in this process is not very wide. A solution standing 1° on Twaddell's hydrometer, specific gravity 1·005 [see *ante*, p. 130], is not more than safe for such goods; while that of half a degree is scarcely sufficient for the first operation of stout cloth, unless it is packed more loosely than usual. [Other mechanical arrangements than this are now adopted, as we have explained and illustrated at p. 126, Fig. 89, *ante*]. When the vessel is first set with fresh solution of bleaching powder, there is little difficulty if the character of the powder be known; but when the goods are retired (withdrawn) from the steeping vessels, they leave a portion of bleaching liquor behind, unexhausted, which must be taken into account in restoring the liquor to the requisite strength for the next parcel. The chlorimeter must, therefore, be applied every time that fresh goods are put into the liquid. It must consequently be entrusted to persons who may not be expert either in figures or in chemical manipulation; hence all the processes (previously) described are too delicate and tedious.

"I introduced another into our establishment some years ago, which has been in regular use ever since; and by which the testing is performed in an instant. It depends on the

depth of colour of the peracetate of iron [see *ante*, p. 112]. A solution is formed of protochloride of iron, by dissolving cast-iron turnings in muriatic (hydrochloric) acid, of half the usual strength. To ensure perfect saturation, a large excess of iron is kept for some time in contact with the solution, at the heat of boiling water. One measure of this solution, at 40° Twaddell [see *ante*, p. 130], or of specific gravity 1·20, is mixed with one of (the best commercial) acetic acid. That forms the proof solution. If mixed with six or eight parts of water, it is quite colourless; but chloride of lime occasions with it the production of peracetate of iron, which has a peculiarly intense red colour.

"A set of phials is procured, twelve in number, all of the same diameter. A quantity of the proof solution, equal to one-ninth of their capacity, is put into each; and then they are filled up with bleaching liquor of various strengths—the first at one-twelfth of a degree of Twaddell; the second, two-twelfths; the third, three-twelfths; and so on, to twelve-twelfths, or one degree. They are then corked up, and arranged together, two-and-two, on a piece of wood, in holes drilled to suit them. (This wood is simply a frame to hold the bottles.) We have thus a series of phials, showing the shades of colour which these various solutions are capable of producing. To ascertain the strength of an unknown, and partially exhausted, bleaching liquor, the proof solution of iron is put into a phial, similar to those in the instrument (the preceding arranged frames of bottles), up to a certain mark (equal to) one-ninth of the whole (that is, its capacity). The phial is then filled up with the unknown bleaching liquor, shaken, and placed beside that one in the instrument which most resembles it (that is, in depth of colour). The number of that phial is its strength, in twelfths of a degree of the hydrometer." Mr. Crum adds a description of his method of keeping up the strength of his bleaching liquors, after testing the amount of exhaustion or relative strength in any particular case, by the addition of a certain number of measures of a kind of stock liquor, depending on the indications of the method we have described; but, as his explanation depends, for its value, on the use of a certain-sized vessel, such as he employed in his works at Thornliebank, near Glasgow; and as such would be of comparatively little value to most, if any, of our readers, we shall not further quote his directions.

Now, this plan of ascertaining the strength of a bleaching liquor is as ingenious as it is simple; and is so easy of adoption, that it may be placed in the hands of any one, who, although destitute of chemical knowledge, can yet, with the use of this, become a competent judge of all practical points of importance to him.

More exact methods of chlorimetry, or the available proportion of chlorine, must be followed by those who buy bleaching powder on the large scale. By long practice and large purchases, we did not find ourselves far wrong in estimating its value; but may have been greatly mistaken in the estimate we formed in that respect. Practically, we were rarely wrong; but such a guide is most fallacious, and should, except under very rare circumstances, not be trusted to. One of the simplest methods with which we are acquainted, is that proposed according to the system of division, as regards volumetric analysis, by Mr. J. J. Griffin; although, in some quarters, his ideas have not found favour. He divides all solutions into portions of a gallon, equal to 70,000 grains avoirdupois, and denominates the tenth part of that, or an imperial pound of water, as a decigallon. This is a most convenient plan in many respects; because, in most of our manufacturing establishments, the gallon of water is a unit of measurement. His division of this, in regard to volumetric analysis, is stated as follows in his *Chemical Handicraft*. The English gallon contains ten pounds of water. The measure of one pound of water is (according to his system) a decigallon. The grains of water in a decigallon are 7,000. If we take, as a unit of measurement, the bulk of seven grains of water, and call it a *septem*, we have, in the decigallon, 1,000 septems.

With these explanatory remarks, his directions for estimating the amount of free chlorine available as a bleaching agent, given as follows, will be intelligible. He directs:—

Estimation of Chlorine in Bleaching Powder.

Take 100 grains of bleaching powder, grind it in a flat mortar with a good spout. When it is finely ground, add water, mix it well, allow it to settle a little, and then decant the thin portion of the turbid (thick) liquor into a decigallon measuring-flask (which is a flask graduated according to the measure we have named). Add more water to the powder in the mortar, grind again, and decant as before. When the bleaching powder has thus, by several affusions, been all brought into the bottle, dilute the mixture to one decigallon; shake it well, and measure off 100 septems, by a bulb pipette (easily obtained at the instrument-maker's), into a mixing-jar for testing. Meanwhile, fill a Mohr's burette (also sold at all instrument-makers) with an arsenical solution * * * * containing 69·718 grains of arsenious acid (pure white arsenic, as sold in the shops), dissolved in excess of carbonate of soda, in a decigallon. This solution is equivalent to fifty grains of chlorine; so that one septem of it indicates 0·05 grains of chlorine—that is, 100 septems is equal to five grains of chlorine. The solution is then run into a mixing-jar. The indicator of the effects of the chloride solution, examined, is a clear decoction of starch (say arrowroot boiled in water, and kept till cold), with which a little iodide of potassium has been mixed. Drops of this indicator are put upon a testing-plate, which may even be a common china plate; and, from time to time, drops of the mixture of bleaching powder and arsenic are to be transferred, by means of a decanting tube, on to the plate. At first the indicator (that is, the starch and iodide of potassium solution) becomes greenish-blue, and then blue,

which abates in colour with succeeding drops of the mixture, until at last the drops of the latter produce no change on the indicator, when the operation is at an end.

Mr. Griffin states the results, according to his method, to be arrived at as follows:—Observe how many septems of the test-liquor (according to his mode of preparation) have been used. Multiply that number by 0·5, or divide it by 2 (which, by the decimal system, amounts to the same thing); the product is the per-centage of chlorine in the bleaching powder. Thus, if 60 septems are used, the per-centage of (free) chlorine is 30.

As already previously noticed, arsenious acid—that is, white arsenic and ordinary copperas (sulphate of iron), have long been both, but separately, considered to be good tests of the presence of free chlorine in bleaching powder. Quoting from the article by Mr. Walter Crum, of Glasgow, or rather Thornliebank, near that city, and already referred to at p. 162, *ante*, we find the following observations, which are continuous, and partly incorporative, of what we have already brought before our readers. Mr. Crum observes—

"M. Gay Lussac prefers * * * the arsenious acid (that is, choosing between that test, the ferrocyanide of potassium, and protonitrate of mercury), from the precision of its indication. He retains the same basis of measurement as for the test of indigo alone [see *ante*, p. 162]; that is, he takes for unity the discolouring power of one volume of chlorine, dissolved in an equal volume of water. That is divided into 100 equal parts. The arsenious (acid) solution is prepared of a strength just sufficient to destroy an equal volume of chlorine gas, or of the chlorine solution. If we take a constant quantity of the unknown solution of chlorine, say ten cubic centimeters (that is, nearly equal to 155 grains of water, at 62°), and pour into it the arsenious solution till the chlorine is gone (or neutralised), the force of the chlorine solution will be in proportion to the quantity of arsenic (arsenious acid) employed. If the 100 measures of (the) solution of chloride (of lime) have taken 100 measures of the arsenious solution, then it has the strength of 100; and it contains its own volume of chlorine gas. If only 80, then it is called of the strength of 80 degrees, and it contains $\frac{80}{100}$ or 0·80 of its bulk of chlorine gas. But this mode of operating would not give good results; for the muriatic (hydrochloric) acid which is employed to dissolve the arsenic, and without which the action of the chlorine would be incomplete, disengages the chlorine from its fixed combination with lime faster than it has arsenic to act upon, and thus a portion escapes into the air. The solution of bleaching powder must, therefore, be poured by degrees into the arsenious solution; and as the strength of the chlorine solution is then inversely as the quantity employed, a calculation is necessary, or a table has previously to be prepared, by the inspection of which, the results may at once be obtained. The point of solution of the arsenic is indicated by a blue tinge, which is given to the arsenious solution by indigo. This substance is not affected by chlorine so long as arsenious acid is left (present); after which (that is, the neutralisation of the arsenious acid), a single drop of chlorine causes it (the colour of the indigo) to disappear."

We have quoted the preceding, although not very lucid, explanation as the basis, so far as we can see, of the method that we have already recommended, as proposed by Mr. Griffin. But knowing, as every practical chemist must do, the uncertainty of the composition, according to chemical laws, of chloride of lime, we have no hesitation in stating, that any method of chlorimetry yet propounded is deficient in really valuable and practicable results. At the same time, as both buyer and seller agree in relation to any particular plan of analysis, neither party has any reason to complain.

The method of cotton-bleaching essentially depends on four separate and successive processes, some of which are frequently repeated, although each is independent of the other. The first step is, to remove all resinous and fatty matters that are invariably present on raw cotton; and if not removed would prevent the success of subsequent processes. This operation is termed scouring; and it is effected by heat, and alkaline liquids, made by dissolving lime or soda in water. The action of chloride of lime, which, in part, removes the colour, is a second essential: following which, is that of immersing either goods or yarn in a solution of acid-water, which liberates the chlorine from the chloride of lime of the preceding process, perfecting the whitening of the yarn or goods. The last step is abundant washing, to free the articles bleached from every matter soluble in water.

There are, however, many intermediate steps, and several modifications of, and additions to, the processes named, as absolutely essential in bleaching, whether of goods or yarns. Calicoes, for example, are singed; that is, they are passed over the flame of gas, or over a red-hot iron plate, to remove all nap or projecting fibre from their surface; and when so prepared, they have a surface which much more evenly takes the colour in the subsequent process of printing. One of the most recent methods of effecting this result, is that of causing the gas-flame, produced by the combustion of coal-gas and air, to impinge on the cloth, which effects the result very speedily, and is strictly under control. It has also the advantage of great economy—a cubic foot of gas being capable of singeing a whole piece of calico.

To economise both time and labour, the continuous system is now very generally adopted in bleaching calicoes for printing purposes. The mechanical arrangements used have been already illustrated at p. 126, Fig. 89, *ante*. The pieces are tacked end to end by girls, and then folded together. A series of vats, with rollers, as shown in the engraving just referred to, is arranged, so that scouring, washing, immersing in the chloride of lime solution, souring, and each operation requisite in bleaching, are successively undergone by the cloth. The operation

requires little attention, being self-acting throughout: the calico is then gradually drawn from one end of the arrangement to the other, and at last dried by steam-heat. The first step is the removal of all resinous and other matters by hot solution of lime. This is commonly effected by "forcing the scouring liquor to circulate uniformly through the cloth, by means of pressure, that causes much more speedy and regular removal of the impurities of the material," observes Dr. Calvert, "than by any other method." He also adds—"Great improvements are stated to have been effected on the continent, in the bleaching of gray calicoes, by the following process, by which the pieces, instead of being dipped in cold water, as they usually are on their arrival at the bleacher's, are soaked in water at a temperature of 140°, to which a small quantity of malt is added; this causes the conversion of the starch in the pieces into dextrine or sugar, thus facilitating greatly the removal of the size from the warps."

It is of the greatest importance, in calico-bleaching for printing purposes, that all fatty and other impurities should be absolutely removed; for, if present on the cloth during printing or dyeing operations, they would be sure to cause spots, and print unevenly. The application of the scouring liquor, and washing by the dash-wheel (already described at p. 126, *ante*), are, therefore, of primary importance in the early stages of calico-bleaching.

When this has been completely effected, immersion in an acid solution, made by adding as much sulphuric acid as renders the water of the sourness of lemon-juice, follows. It would, doubtless, be much better to use muriatic (hydrochloric) acid, as all its salts are soluble in water to almost any extent, comparatively speaking; whilst the sulphates, formed by using sulphuric acid, are not; as, for example, the sulphate of lime, that is sure to be a product of the lime lixiviation. After washing from all trace of acid, the cloth should next be passed through a hot alkaline (soda) liquor—not too caustic, however, for that would injure the fibre of fine goods.

Supposing the perfect removal of all matters that can be rendered soluble has been effected, the next step is immersion in the chloride of lime; and the strength and clearness of this are matters of the highest importance. In regard to the strength, we refer our readers to the remarks of Mr. Walter Crum, one of the largest calico-printers. They are given at p. 162, *ante;* at which will be found directions for regulating and testing the strength according to Twaddell's hydrometer. A stock solution of chloride of lime is made, and allowed to settle. The clear portion is then drawn off for use; and care should be taken that no lumps are present, for, if these get on the cloth, they would, in the subsequent process, burn it into holes. This is a common cause of injury both to cloth and yarn, and one that frequently causes loss; for, of course, a piece so injured is absolutely valueless for commercial purposes.

After the cloth is well imbued with the chloride solution, it is passed into one of acid and water; muriatic acid being preferable, for reasons already stated. The acid decomposes the bleaching powder, setting free the chlorine, which thus immediately and powerfully acts on the fibre, producing a pure white. It also dissolves away iron, which would give a yellow tinge to the goods by subsequent peroxidation, besides being injurious, if present as a mordant, in subsequent operations of printing or dyeing. Abundant washing succeeds, followed by drying, when the goods are finished, if intended for printing; but require a slight bluing if to be sent out as white articles. The latter operation is identical in character with the similar one of domestic practice after washing, &c.

Yarn-bleaching is carried on after precisely the same principles as those just described in reference to cotton-cloth bleaching; but, of course, the mechanical details vary, owing to the very different external characteristics of each article. The hanks are tied with cord loosely at their two external ends, so as to prevent one hank from getting its fibres entangled more than possible with another. The material is then passed through the various processes of "scouring," souring, immersion in chloride of lime, souring, &c., as previously detailed; and, after final washing, is passed through a bluing liquor, to remove, or rather to neutralise, the yellow tint, that would otherwise appear after a time. In the case of most yarns, to be applied to manufacturing purposes other than those of calico-weaving (which, in all cases, is effected with unbleached yarn), they are neatly twisted up, and put into a press, so as to form ten-pound bundles, in which condition both single and doubled yarns are usually sold.

We have omitted to notice many particulars respecting the finishing of both goods and yarns sold in the bleached state by the manufacturers, as these, in the case of calico, would fall under the head of Calendering, which, with the aid of wheat-starch, in the form of dressing, gives the cloth an even and glossy appearance. Of course, such details are apart from the general object of this work; and similar questions in respect to yarns, sewing cotton, &c., as being mostly more mechanical in their nature, must be left untouched by us; for they would necessarily lead us into many matters that should more properly come under consideration in a work on spinning and weaving textile fabrics.

Linen and hempen fibres generally may be bleached by processes already described; but for "Irish linens," and "cambrics," the old method of "grass-bleaching"—that is, by the action of the air and moisture—is still employed. In the early part of this article on bleaching we have described the old method, as applied to cotton; and as the details and principles of those adopted in bleaching linen are similar, when the open-air plan is adopted, we need not again go into further explanation.

Wool and silk scouring, and bleaching, and that of mixed fabrics of cotton and wool, differ much, in principle and detail, from the processes

just previously described; for neither acid for souring, nor chloride of lime for decolouration, are admissible. Wool contains, on the surface of its fibres, an oily and adhesive matter, that resists the unaided action of water, either hot or cold; but which can be removed by alkalies, such as pearlash (potash) or soda. But both these, as a caustic, would, if applied, materially injure the tenacity of the fibre, and unnecessarily decrease the weight of the wool scoured by them; hence a double source of loss would be occasioned. If practicable, stale urine, by affording ammonia, is an excellent and safe source of alkali for such purposes; but, usually, the supply is too limited to permit of its exclusive use; and soap, with ordinary "washing soda," in crystals, are employed in solution with hot water. By such means the fatty matters are readily removed, and the surface of the fibre left free for bleaching or dyeing purposes, abundant washing in water being had recourse to. The temperature of the soap and soda solution is important, for two reasons; one being, that too high a temperature would shrink the fibre, yarn, or goods; and the other is found in the fact, that a high heat so far stimulates the action, both of the soap and soda, as to injure the articles. A heat but little over what the hand can bear—say not exceeding about 145°—is sufficient; and it is safest to judge of this by using the thermometer (see *ante*, p. 128). It is usual to stretch all woollen articles by mechanical means, as much as possible, during the process of scouring, so as to prevent contraction, and also the action of the felting property, by virtue of which each fibre tends to unite firmly to those adjacent to it—a circumstance of great value during the finishing of cloth, but a cause of much loss under other conditions. Some kinds of wool lose enormously during scouring—we have known as much as 30 per cent.; and this, on high-priced wool, is a matter of great importance, and causes much loss to the manufacturer, who, therefore, takes every proper precaution to keep it within the narrowest limits possible.

Silk is scoured by similar means to those adopted for wool; but, as the individual fibres are much more delicate and finer, greater care is required, both in the chemical and mechanical details; more especially as any loss it sustains increases, in pecuniary value, many times above that found in even the cost of the best wool.

Although chlorine is useless for bleaching any but vegetable materials, we have, in another agent, *sulphurous acid*, that which supplies our want. Sulphurous acid contains one equivalent less of oxygen than sulphuric acid; and is readily produced by burning sulphur or brimstone in air. As is well known, it has a most suffocating odour, arising from the acid fumes. Under the formerly adopted method, either woollen or silken goods were, after scouring and moistening, placed in a close chamber, in which was burning sulphur—so folded, or rather hung, that the fumes had free access to every part of them. Another method was that of using liquid sulphurous acid, by decomposing in water certain salts, that thus afford sulphate of soda and the acid, both dissolved in the liquid. By the method of Mr. Thom, of Manchester—now of general use, and especially of value in mixtures of cotton and wool, as *mousselines-de-laines*—the goods are passed over a number of rollers, in an air-tight chamber filled with sulphurous fumes, produced by the combustion of sulphur; and their whitening is effected in almost as many minutes as formerly hours were needed. On removal from any of these sulphuring arrangements, the goods are carefully washed; and, if to be sold in the white state, are slightly blued, like cotton, with indigo, to remove or mask any yellow shade they may possess, or are likely to attain in time.

Such are the chief methods and processes in modern use for bleaching or whitening cotton, linen, woollen, and silken yarns or fabrics. Within the last fifty years, numerous improvements have successively led to the perfection that now characterises the various operations we have described. In former days, when calico-printing was in its infancy, and the principles on which it was conducted were more mechanical than scientific (being also exceedingly rough in their results), an imperfectly bleached piece of calico was not so much objected to. But when chemistry, in all the delicacy of its precision in effect, and in the variety of colours also of an exceedingly delicate character, directs, or is involved in, the operations of the calico-printer, the cloth must be as perfectly free as possible from impurity of any kind, or it would be impossible to produce anything like a good result. This is especially seen in connection with the use of coal-tar colours, which, in calico-printing, as in dyeing, have greatly taken the place of colours of vegetable origin. We must also bear in mind the enormous expansion of our manufactures of cotton, rendered consequent on the great demand that exists for them in many parts of the world. Our amount of production, of recent years, has increased some hundredfold. From 1830 to 1857, the number of printed goods rose, from 200,000 pieces annually, to 27,000,000 in the last year. Of course, the civil war in America paralysed this, and many other branches of industry; from which, however, they have gradually recovered: still, even with all these detrimental circumstances, the trade has constantly made great progress beyond that previously stated. As we shall observe when comparing the old and new methods, in the succeeding article on Calico-printing, the old method was absolutely incapable of supplying more than a very limited demand—that is, when block-printing alone was had recourse to. The introduction of cylinder-printing, with one roller, was a great improvement; but now, by numerous rollers, several colours are simultaneously printed by one machine with astonishing rapidity and beauty. Thus, first, the improvements in the methods of bleaching, arising out of the discovery of chloride of lime, laid the foundation of the immense cotton manufacture of our kingdom, so far as it related to supplying the material of the

printer. Improvements in his processes led to further demands on the bleacher; and so each branch of the art reacted one on the other, urging on, and producing, wonderful improvements. As one process advanced in beauty and exactness, it made fresh call on the other; hence, as we have already said, the great, rapid, and mature growth of the arts of dyeing, bleaching, etc.

Calico-Printing.

In the Introduction to the first volume of this work the early history of the art of calico-printing has been given, including the old method of block-printing, and the more modern one of printing by the cylinder as now universally adopted; and generally the process has been fully described. It will be unnecessary to enter more fully into such details. We therefore proceed to describe some accessory matters of general interest in regard to cylinder printing.

The mode of engraving rollers is most ingenious; and considering the difficulties that arise in the ordinary method of engraving curved surfaces, a surprising triumph of perseverance and skill. The length of the roller is suited to the width of the piece to be printed: and its diameter varies from about three to, now, nearly fifteen inches; the latter being made of a length of forty-four inches. The pantograph is employed for this purpose, as, by its means, a large pattern may be transferred to a roller, on which it is engraved on a much smaller space with all possible accuracy. It will be impossible to illustrate this ingenious plan, which we much regret, as we have watched it with great pleasure at the printing-works of Messrs. Daglish, at Campsie, near Glasgow. After the figure has once been outlined on the roller, it can be readily deepened or cut out to any extent by means of steel engraving tools, or the action of dilute nitric acid, after the usual plan adopted in copper-plate engraving on flat surfaces. We are indebted to the late Dr. Calvert (whose work has been already frequently quoted) for the following particulars in respect to roller engraving during the last few years. He says:—"This branch of calico-printing has made great progress. Not only have the engravings acquired sharper outlines, and finer details, but the methods of engraving have greatly multiplied. I may cite, as instances, the application of the principle of the pantograph, so as to trace patterns on the surface of copper rollers, by Messrs. Smith, who, as well as Messrs. Lockett, Sons, and Leake, have effected such improvements since the first pantograph was exhibited in 1855, as to render this mode of engraving most useful to the art of calico-printing. Calico-printers have also extensively availed themselves of Mr. Lockett's improvements for producing the groundwork of prints, or, as they are termed, 'covers,' by applying 'eccentric engraving,' or etching, which produces, with facility, most complicated patterns on a varnished roller, by means of a diamond point guided by machinery. Another improvement, highly interesting in a scientific point of view, is the application of galvanism to the diamond-tracer, by Mr. G. Gaeff, of Paris, which is, doubtless, destined to exercise considerable influence upon the progress of calico-printing. By combining the galvanic action with an eccentric motion, most beautiful and delicate engravings can be produced. This is done by tracing the patterns with varnish on a zinc cylinder, which is so placed in the engraving machine, that as a needle passes over its surface, and comes in contact with the zinc, the galvanic current is established; and, by simple machinery, causes the diamond to trace the corresponding patterns on the copper rollers. The communication is so rapid and precise, that a great saving of time is effected. But if mechanical art has greatly assisted the engraver, chemistry has rendered him equally important service, by enabling him to abandon costly and cumbrous modes of impressing, by force, the design on the cylinder; substituting for them a great number of etching processes. By some of these processes, as by every other addition to the resources of the engraver, an entirely new and beautiful class of engravings is produced, unattainable by any other known means. For instance, owing to various improvements, rollers of forty-three inches in circumference, and forty-four inches long, have been introduced, enabling the calico-printer to produce, cheaply, large furniture patterns."

The former method of cylinder or roller engraving, for the calico-printer, was of two kinds. "In the first and original method, the exact circumference of the cylinder is taken by a piece of paper; and on this paper is copied the design, so chosen that exactly one repetition, or a complete number of repetitions, of the design may equal the circumference of the cylinder. On this paper the device is sketched, and is then transferred to the surface of the cylinder, in a manner sufficiently distinct to guide the engraver in engraving it. In a more modern method, advantage is taken of the valuable principle by which steel plates are multiplied. A small steel cylinder, about three inches long by one in diameter, is engraved with as much of the device as its surface will contain; this being done while the steel is in the soft state. The steel is then hardened, and pressed, or rolled very forcibly, against a soft steel cylinder, by which an obverse impression is given to the latter, that is raised instead of depressed. As the original die was at first in a soft, and then in a hard, state, so this second cylinder, which is called the mill, receives its impression while in a soft state, and is then hardened before being applied to its subsequent purpose. This purpose is, to impress the device upon the surface of the large (copper) cylinder, which is to be employed in printing. The mill is applied successively to different parts of the cylinder, so as to give an engraved surface to the whole."

A perusal of this description of the former methods of producing printing rollers, and a comparison with those now adopted, will show the force and truth of Dr. Calvert's remarks, as

already quoted, where he observes, that "chemistry has rendered him (the engraver) equally important service, by enabling him to abandon costly and cumbrous modes of impressing, by force, the design on the cylinder; substituting for them a great number of etching processes."

We have thus described the chief mechanical processes involved in calico-printing, so far as verbal description can convey an idea of the machinery employed for the purpose. The art is really an adaptation of the chemical and general principles of dyeing on parts of surface, the division of effect being dependent on such mechanical arrangements as we have endeavoured to describe. But it is impossible to do justice to the ingenuity that has been evinced in bringing the art to its present condition. It has been remarked that there is no poetry in science; but this has been said by those ignorant of philosophy. The study of a common print dress, used even by the servants of our households, has every element that can render prose or poetry acceptable to the imagination and judgment. The history of its earliest ancestry mixes us up with Phœnicia, Egypt, India, Greece, Rome, Spain, and the barbaric North of Europe; for, from the first, we may gather the early idea of Tyrian purple dyeing; from the second, the first application of the use of mordants; from the third, the production and use of the richest dye-stuffs, that now tend to render our court pageants gorgeous—just as, formerly, the savage, with uneducated taste, equally delighted his limited views of art-production. Greece, Rome, and Spain, in their ancient condition, are even now admired, by what we find as Pompeiian remains, for colour-production; and the latter serve as models for the "unpoetic" calico-printer; but who, in his turn, excites just as much pleasurable feeling of beauty and taste as did the art-followers of the countries we now speak of, existent, as nations, 2,000 years ago. It has been well said, that fashion repeats itself; and it must do so, simply because human nature possesses a unity of mind that, despite clime or circumstances of any kind which may modify or influence its originality, still asserts its prerogative. If our ancestors in Britain ornamented their bodies by woad, our court ladies, of the present day, simply remove the same ornament from the skin to an external dress. If the savage of Africa, or the South Sea Islands, "paints" or daubs his hair with ochre, the refined lady of Europe either assumes the golden tint by chemical means, as taught, unfortunately, by modern science, or avails herself of the ostrich or bird of paradise feather, to decorate her hair. But identity of colour throughout dress suggests a monotonous effect; hence contrasts became desired. Yellow and red, therefore, by such contrast as modern science explains, please those whose ideas of taste are crude. Gradually, as "refinement" became regnant, these colours were toned down. Purple, orange, brown, blue, lavender, mauve, Magenta, etc., thus become indices of the popular taste in colour, and are equally an index of progressive civilisation; because, as the tints of natural, but especially vegetable, productions—*e.g.*, flowers—must be perfect, our attempts to imitate them indicate an approach to that perfection which nature, in all its developments, possesses. Now, the art with which we have had to deal is pre-eminently beyond dyeing proper—approximative, in its effects, to those of nature. How much therefore, of the poetry of nature is mixed up with the rigid, and, apparently, unpoetic aspects of the art!

However much science has done to perfect the processes of calico-printing, and without which any ideas of art would have been of no avail; still, the study of the "fine arts" has, on the other hand, stimulated science. "Art proper," and "science proper," have, therefore, practically become merged in one object; and, as we have already observed, for this result we are much indebted to the establishment of Schools of Design, now so numerous throughout the kingdom. It is, nevertheless, remarkable that originality of design, in most branches of modern manufacture, has but little advanced beyond the standard published twenty centuries ago. The parsley-leaf pattern of Peel, the origin of calico-printing, is, no doubt, of so ancient an origin, that Adam may have seen its first beauties; and, indeed, we learn that the first art-design in dress was of a vegetable nature—to wit, fig-leaves. But none of our modern designs please the eye so well as those we now admire in the ancient mosaic, and cognate works of Southern Europe—that is, of Greece and Rome. Are we to infer that human nature had, at the periods we now refer to, gained its highest development in respect to art-production? Or is there, at the present day, too *practical*, too devoted an adherence to the *cui bono*—that is, a pandering to a low taste that best pays?

We by no means lend credence to such an opinion. Within our own circle of acquaintance in the districts in which calico-printing is carried on, and of those by whom it is pursued, we could point out the best patrons of painting, engraving, and music, as domestic recreations, or for the ornamentation of households—men who, early trained to business habits, have combined, with all its exclusiveism, a love of that which refines both head and heart—men, in fact, who whilst making unto themselves "friends of the mammon of unrighteousness," are possessed of every quality that distinguishes eminence, moral and mental, from mediocrity and "low inferiority." We can only account, therefore, for what we may call our backward, yet rapidly advancing, state of art design to the previous want of an educated taste amongst the masses; but which is now giving way to an improved state of things.

We have made this slight digression from the practical part of our subject, simply because—although it may seem apart from the general object of our work—it really lies at the foundation of all that relates to the art with which we are now dealing; and commend to our readers, both general and practical, a consideration of the various matters, of which we have only offered imperfect and crude suggestions.

We now turn to consider the chemical questions involved in calico-printing, and the general details of its processes.

Calico-printing may be considered as an application of the various processes of dyeing on parts or places, instead of the entire surface of goods; and this partial dyeing is that which produces its pleasing effects. As we have already noticed, the early attempts at the art were crude indeed; but by persevering adaptation of chemical and mechanical science, we have at last attained to great perfection in reproducing, on cotton, wool, and other woven surfaces, designs generally drawn from nature, or modified therefrom.

The remarks that have been generally made in respect to mordants, as fixing vegetable colour, in our article on dyeing, are equally applicable to calico-printing; for, in numerous cases, apart from aniline dyes, the chemical processes are precisely similar—indeed, identical. But, in printing on calicoes, other methods than those we have described are adopted; hence what are termed *resists*, *discharges*, etc.

A very simple instance of the discharge method is found in the operation of Bandana printing. In the first instance, we notice that the cloth is dyed uniformly of one colour, and that the colour is removed by allowing chlorine, as liquid chloride of lime, to run through perforations forming the pattern. Another method is, to print—say, for example, on calico dyed black—by means of blocks as a pattern, the surface of which is wetted with tartaric, citric, or oxalic acid. These, or any of them, at once dissolve the oxide of iron that has produced the black colour by union with the tannin of the astringent matter, as from sumac, logwood, etc. On this solution being applied, the cause of the black being removed, its effect ceases; and hence the production of white spots on a black ground, resulting from the "discharging" action of the acid.

By the action of mordants, some very fine effects in calico-printing are produced. We shall confine our attention, for the moment, to the methods adopted in what are called madder styles. It has been frequently noticed, in the preceding pages, especially when we treated on red dyes, that madder not only affords a red colour from one, but also from several of its principles. Madder, treated by sulphuric acid, yields garancine; but purpurine and alizarine (see *ante*, p. 101) are also its products. Hence, by the proper use of the madder as a dye-stuff, containing, as it does, also tannin, red, lilacs, and numerous other shades may be obtained simultaneously on calico; the acetates of iron and alumina being used as mordants, the former affording all tints from lilac to black, and the alumina salt, those of a red shade. A mixture, again, of these mordants on the cloth, gives another series of colours, varying from a brown to a chocolate, or rather varieties of the latter.

Now, this is one of the most interesting features of calico-printing as an art; and, to those unacquainted with the chemistry of the process, it is certainly one of the most astonishing. A piece of calico shall have printed on it a number of patterns or devices that are invisible, or nearly so; and yet this, immersed in a bath of madder, will become of different colours in its various devices. But the science of this affair is exceedingly simple; and is thus:—madder in solution will afford, with iron salts, tints of a blue, and, with alumina salts, those of a red hue. In proportion as we use in quantity each of these salts, more or less, we increase or deepen that tint, and have thus a great range of colours, from slate, or blue, to black, with iron mordants, and from pink to red with alumina salts; and if we mix these mordants successively, or rather superimpose them, we gain a result depending, in the colours produced, on those laws of light that we explained at p. 86, *ante*, in regard to the production of greens and other compound colours.

But to effect this the mordants must be thickened; because, if merely printed on the cloth in a state of solution, they would run in all directions on touching the calico, and make literally a complete "mess"—indeed, no proper pattern could thus be produced. For this and other purposes, hereafter to be mentioned, thickeners are required, and these are of various materials: an epitome and description of them being conveniently conveyed to our readers by a quotation from Dr. Calvert's work, that we have already made liberal use of. His remarks on these *media* are as follow:—

"Thickeners can be classed under two heads: Firstly, those which are merely employed to give proper consistency to the colouring matter [that is, in topical printing, of which we shall presently speak]; and, secondly, those which not only fulfil that purpose, but also serve to fix the colours on the cloth. As I intend to refer to the second class when speaking of the pigment style of printing [which we shall also presently deal with], I shall here confine my remarks to the first class of thickening substances. I may, however, just state, that egg albumen is obtained by evaporating in the air, at a moderate temperature, the white of eggs; blood albumen, by heating, in the same manner, the serum (or white portion) of blood, separated from the red colouring matter called hæmatosin; lactarine, by curdling milk with an acid or rennet, collecting the curd caseine, washing and drying it; and gluten, by making wheaten flour into a thick dough, and washing the same under a gentle stream of water, which removes the starch, and leaves the elastic substance, called gluten. The first class of thickeners consists of wheaten flour, wheaten starch, farina, sago, gum-arabic, gum-senegal, etc.; and also of a variety of artificial gums, or preparations of flour and starch, which were called into use in consequence of the great increase in the price of gum-arabic, arising from its extensive employment in printing. Thus farina (potato starch), heated to a temperature of 250° to 300°, and thereby rendered soluble as a gum, became extensively employed as a substitute; and, of late years, it has assumed an important place in the list of materials used by calico-printers. To

effect this curious change at the present day, farina is heated to the above temperature, either in a revolving cylinder, or in iron troughs placed in a stove for several hours, when it acquires an umber colour, and becomes soluble in water. This change is entirely a molecular one (that is, amongst its particles), as the raw and calcined farina has the same (chemical) composition: notwithstanding which, farina gives a blue colour with iodine; and when calcined, a purple with the same substance. As the colour of calcined farina is an objection to its employment in many instances, it was a great desideratum to find a process for its conversion at such a low temperature as to leave the converted farina nearly colourless. This was first effected in 1838, by M. Payen, who found that if, to four hundred parts of dry farina, one part of nitric acid, at 1·40 (specific gravity), was added, after having been diluted with water, to form with the farina a hard paste, and this was dried slowly, and heated in a close chamber for twenty hours, at a temperature of 200°, a nearly white farina was obtained. It is interesting to observe how so small a quantity as a few thousandths of acid can effect this great molecular change. Since that time, many processes have been devised to obtain the same end: for instance, the employment of lactic acid by Mr. Edward Hunt; of oxalic and tartaric acid by others; and, lastly, a process by Mr. Charles O'Neil, which is valuable, as it enables him to convert insoluble farina into *dextrine*, without any change of colour. This he effects by subjecting starch, farina, and other amylaceous (starch-like) substances to the chemical action of muriatic (hydrochloric) acid gas, or other acid gas or vapour, in a cylinder, the exterior of which is surrounded by an atmosphere of steam. This beautiful preparation has extended the employment of soluble farina as a substitute for gum-arabic, the colour which was inseparable from farina, previous to this discovery, excluding its use in many instances. As calico-printing, in its present extraordinary development, requires thousands of tons of soluble materials for thickening the mordants and colours used, a great variety of this class of artificial gums is prepared to meet these requirements. Thus, besides farina, sago, rice, slimes, and wheaten flour are used; the latter, when heated, generally bears the name of British gum, which differs from calcined farina in being soluble in water only at a boiling temperature."

The preceding quotation will serve to point out how many apparently subsidiary or minor matters are of importance in the art under consideration. Indeed, taking the various processes involved in it collectively into consideration, we shall, perhaps, find few, if any, other arts dependent on applied science that involve so great a variety of minute details for successful exercise or pursuit.

Returning to the question of mordants, the solutions of these are thickened by some of the substances just described, and applied to the surface of the cloth. The latter is then dyed in a bath of garancine, alizarine, or purpurine; and at such parts as the mordants have been applied, colours are produced according to the mordant that there is fixed. After remaining in the vat for about two hours, the cloth is well washed in the washing-machine, or dash-wheel, and afterwards immersed in a hot solution of soap, to remove all traces of colour from those parts where the mordant has not been applied. The white parts are still further brightened by the use of the solution of alkaline hypochlorite of soda, which has a comparatively feeble action, and is therefore safer than one of chloride of lime, a little sulphate of zinc being added. After washing, the goods are separately, in each piece, passed through some flour mixed with water, by way of giving them a glossy appearance, when they are afterwards passed between rollers and calendered. They then present the appearance familiarly known in the "prints" of our shops.

For the sake of maintaining the continuity of the process we have described, we have, till now, omitted a very important part, called *ageing*—an operation on which, in fact, depends much of the brilliancy and colour of prints that are dyed by the method just related; and which, in former times, was an uncertain process, because its science was little, if at all, known.

When speaking of dyeing black, at p. 112, *ante*, by means of astringent matter and a protosalt of iron, we stated that exposure to the atmosphere was essential to the conversion of the protoxide of that metal into the sesquioxide, which is a high state of oxidation, and one essential to the production of black by the action of tannic acid on the iron. In dyeing calico, it was formerly necessary to expose the cloth after impregnation or printing with the mordant, either of acetate of alumina or of iron, for some days to the open air, for the double purpose of peroxidising the iron, and of facilitating the separation of the acetic acid from the acetate of alumina—both results being necessary for success in the subsequent operation of passing it through the madder bath, to fix the colour on the mordanted parts. Moisture is also an essential element in this process.

By a very ingenious arrangement, air and steam are made to perform these operations, resulting in "ageing;" and the late Mr. Walter Crum, of Thornliebank (whom we already have frequently quoted), was the first to carry out the plan we shall presently describe. The stranger visiting a print-work will see a tall erection, like an immense wooden box, or chamber, near the works; and, at times, will notice steam issuing from the top. Its use and construction will be understood from the following description, by Mr. Crum, of that erected at his works:—

"A building is employed, forty-eight feet long inside, and forty feet high, with a mid-wall from bottom to top, running lengthwise, so as to form two apartments, each eleven feet wide. . . .

"In one of these apartments the goods first receive the moisture they require. Besides the ground-floor, it has two open sparred floors, twenty-six feet apart, upon each of which is fixed a row of ten rollers, all long enough to

contain two pieces of cloth at their breadth. The rollers being threaded, are set at work by means of a small steam-engine; and the goods to be aged, which are at first placed on the ground-floor, are drawn into the chamber above, where they are made to pass over and under each roller—issuing, at last, at the opposite end, where they are folded into bundles, on one (at a time) of the three stages which are placed here. These stages are partially separated from the rest of the chambers by woollen cloths.

"While the goods are traversing these rollers, they are exposed to heat and moisture, furnished to them by steam, which is made to issue gently from three rows of trumpet-mouth openings. The temperature is from 80° to 100° or more—a wet-bulb thermometer indicating, at the same time, 76° to 96°, or always four degrees less than the dry-bulb thermometer. In this arrangement fifty pieces, of twenty-five yards (each), are exposed at one time; and as each piece is a quarter of an hour under the influence of the steam, 200 pieces pass through in an hour. Although workpeople need scarcely ever enter the warmest part of this chamber, a ventilator in the roof is opened when there is any considerable evolution of acetic acid.

"The mordant . . . does not become fully 'aged' by this process alone, although as much so as if it had hung a whole day in cold air. It has received, however, the requisite quantity of moisture (about 7 per cent. of the weight of the printed pieces), and is thereby enabled, if an iron mordant, to take oxygen from the air, and to become changed (with time) into the sesquiacetate, and sesquihydrate of iron. In order to be sufficiently aged, it must be left one or two, or even three days in an atmosphere still warm and moist.

"It had, fortunately, been ascertained long before at Thornliebank, that exposure in single folds after moistening was not necessary. Mr. (Dr.) Graham's experiment on the diffusion of gases through small apertures, had served to suggest, that for the absorption of the small quantity of oxygen required, the goods might as well be wrapped up, and laid in heaps. Accordingly, in the operation in question, the moistened goods are carried in bundles into the building on the opposite side of the mid-wall already mentioned, and deposited there upon the sparred floors, which are placed there at heights corresponding with the stages, in the first apartment, in which the goods are folded down. Upon these floors seven or eight thousand pieces may be laid at a time; and, as each piece is twenty-five yards long, 100 miles is therefore the quantity that can be stored at once. It is necessary, of course, that an elevated temperature, and a corresponding degree of moisture, be preserved in the storing departments, day and night; and 80° is sufficient, with the wet bulb at 76°. To effect that object, a large iron pipe is placed along the floor, underneath, and moderately heated by steam, while a row of small jets, in the same position, are made to project steam directly into the air of the apartment. The whole building is defended from external cold, and, consequently, from condensation of steam, by a warmed entrance-room, and by double iron doors, and a double roof. Small steam-pipes are also placed at other points where they seem to be required; and the apartment with rollers is specially heated, when not in use, by a couple of steam-pipes, which are placed under the ceiling of the ground floor.

"The process of ageing, as thus detailed, was in operation at Thornliebank in the autumn of 1856. About a year afterwards it began to be adopted by other printers; and now it is already in use at most printing establishments in Scotland and Lancashire."

Mr. Crum's establishment had the advantage of having in himself, as its owner, an accomplished practical chemist, to direct all operations; and, perhaps, none in the kingdom is more successfully and scientifically carried on than the Thornliebank printing-works.

In respect to the materials employed in calico-printing, other than those of the aniline kind, to which we shall separately refer, we may observe that they are identical with those employed for ordinary dyeing purposes. The reds are generally produced from madder, or its derivatives, garancine, alizarine, and purpurine, for these give brilliant and fast colours. Indigo is largely employed for blues. To produce white patterns on cloth, with a blue ground, the material is first dyed blue by either of the processes described at p. 136, *ante;* but *before* immersion in the blue vat, etc., the pattern is printed on the white cloth by a solution of sulphate of copper, or blue vitriol. This prevents the indigo from fixing itself at such points on the cloth, because, by the decomposition of the oxide of copper, the indigo is oxidised on the immersion of the fabric in the blue-tub. Now, no other than those surfaces thus affect the cloth, which, when removed from the vat, affords no colour; but which, by exposure to the air, eventually becomes blue; whilst those places on which the copper salt has been deposited remain white.

The process is completed by passing the cloth through a weak acid solution, and subsequent abundant washing. Indigo may be printed direct on the cloth from the cylinder of the machine, after the manner we shall briefly describe. The indigo is first mixed in fine powder, with glucose, lime, and soda; and after being printed in the ordinary way by this mixture, the fabric is passed through a steam atmosphere, by which the indigo is rendered soluble, and attaches itself to the fibre, when, becoming oxidised, it assumes its usual blue colour.

Many of the vegetable colours described under the head of Dyeing, especially "spirit colours," are printed on calico, either by being first mordanted, and then imprinted by the cylinder, and afterwards fixed by steaming, or oxide of tin is first precipitated on the surface, and the colour thickened by means suggested at p. 169, *ante*, and applied to the surface of the cloth. This, therefore, chemically, in process is the same as dyeing, the goods being generally mor-

danted, but the colour only partially applied; that is, at the part in which it is intended to form the pattern. The goods are then steamed, to fix and enliven the colours; hence such are called "steam colours." The depth of colour will depend on the strength of the dye-solution applied to the surface from the cylinder of the machine; and, therefore, the light and dark shades are modified by the dilution or concentration of the dye so applied. A most ingenious method of managing this has been invented. It is that of printing the colour by one roller, and diluting it by another. The latter is covered with gum-water, which is first imprinted on the cloth: when the colour-roller arrives at the same place, the colour is produced of a lighter tint, by dilution, than at any other part of the fabric not so treated.

Of course, various shades of one or more colours can thus be simultaneously printed, a proportionate number of rollers being supplied to the machine.

In former years, the fixing and isolation of a mordant were chiefly effected by the action of a bath of cow-dung, through which the calico was passed, after mordanting and ageing. This is now effected by much simpler and efficient means, by the use of what are called dung-substitutes, which consist of phosphate of soda and lime, that naturally exist in cow-dung, arseniate and arsenite of soda, and the silicate of that alkali. Dr. Calvert remarks, that "by the introduction of dung-substitutes, and improved dunging vats, a great saving of time, labour, and expense has been effected. Thousands of pieces are now done in the same vat, where formerly hundreds only could be treated." Another and important effect of such means is that of removing any excess of colour, and of keeping the unmordanted parts free from the effect of the dye-liquor.

A most beautiful series of results is now obtained by fixing insoluble mineral or other matter on the surface of fabrics in the course of printing. The method is termed pigment printing, and has been long known; but from various difficulties in the way of fixing agents, did not come largely into use until about 1859, when the aniline dyes became greatly patronised. A variety of fixing agents, as albumen obtained from the white of eggs, india-rubber dissolved in mineral naphtha, etc., had been tried; but they all failed, owing to the pigments being scarce and badly manufactured, and for want of a fixing agent suitable in all cases. Aniline colours being adopted, the pattern was printed in albumen or lactarine (the caseine, or cheesy matter of milk), on the fabric. This mordant was afterwards fixed by coagulating it with steam; and the fabric was then passed into a solution of one of the aniline purples. The albumen, or lactarine, speedily took the colour, which, as we have already stated in respect to cotton, is not easily affected by it. Hence the pattern alone became coloured; and, after abundant washing, the operation was completed.

The beauty of colours thus printed by aniline purple, gradually led to the use of Magenta, and others that we have named at p. 123, *ante*. One by one the difficulties of fixing them on cotton were overcome. Mr. Crum, whom we have repeatedly mentioned, proposed a simple and cheap fixing agent in 1859, which consisted of the gluten of wheat flour, allowed to acquire a semi-fluid condition by lengthened exposure to the air, when it becomes soluble in a solution of caustic soda; and, in that form, could be substituted for the albumen or lactarine, already named. But still the processes of thus printing aniline colours were comparatively slow; for, as we have explained, the mordant had first to be printed, and then the cloth was immersed in the aniline dye-bath. It was, therefore, attempted to print the colour directly on the fabric at one operation; and this was effected, in 1860, by the use of animal mordants. Dr. Calvert remarks, on this process, that the "pigment style was fully developed; and an entirely new class of prints was introduced into the market." Being, at that time, resident in Scotland, in the centre of the printing districts, and having personal access to the leading printing establishments, we well remember the impression of beauty that these new productions of printed fabrics produced on our mind; and, when offered in commerce, their sale became enormous. In respect to this, and as regards certain improvements in the fixing agents, we again quote Dr. Calvert, who had so much to do in developing the aniline system of dyeing and calico-printing, and to whose exertions we are nationally so much indebted. He says:—

"Owing to the great extension of this style (the pigment), the cost of the animal mordants became such a serious consideration, as to cause anxious search for other means of fixing the colours; and Mr. Charles Lowe, and myself, having observed, in 1856, that tanning matters would precipitate and render insoluble certain coal-tar colours; and having further observed at the end of 1859, that tannin, when printed on cloth, and submitted to the action of steam, would become fixed, and serve as a mordant for coal-tar colours, we took out a provisional specification on the 10th of December, 1859, for fixing the insoluble tanning compound formed by adding a solution of gall-nuts to a coal-tar colour on cloth, prepared with oxide of tin, or alumina, or other metallic oxides. For various reasons this patent was not proceeded with; but, in the early part of 1861, Mr. Gratrix, with the intelligent and persevering assistance of Messrs. Butterworth and Brooks, of Manchester, succeeded in fixing aniline purples, which, though faster against soap than those printed with albumen, did not so perfectly resist the action of light. The first process used by Mr. Gratrix was, with a very slight modification, the same as that described above; but his second process, which I think he prepared, was the following:—He took cloth prepared with oxide of tin, such as is generally used in steam colours; and, having printed it with a gall-nut solution, submitted it to the action of steam, when the tannin became fixed and insoluble; the pieces were then passed through a dunging liquor,

washed, and dipped in a beck of aniline purple mixed with a little acetic acid. As the bath was gradually carried to the boil, the colour fixed itself on the tannin, and thus produced the print; but as the whites were rather soiled, the pieces were passed into a weak acid bath, or through a solution of printing cleaning-liquor, such as is used for garancine." Numerous other methods have since been devised; and, amongst them, we may especially notice that of M. Onfroy, of Paris, who prints the aniline colours on a black ground, produced by gallic, instead of tannic acid. The colours are mixed with some oxalic acid when they are printed, and this destroys the black, and fixes the aniline dyes.

The preceding explanations, quotations, etc., will show how the art of calico-printing has wonderfully advanced during the last few years, in producing all shades of red, pink, purple, blue, and colours formed by the optical and practical union of these *inter se*, and with yellow. We may notice, however, some sources of green that have not yet been mentioned. One of the most beautiful of these was produced by M. Guignet, and is a form of pigment-printing, by means of the hydrated oxide of chromium (see *ante*, p. 113). His method of producing this beautiful green was, first to form the borate of chromium by fusion of bichromate of potash and boracic acid together. On the mass being dissolved in water, the oxide of chromium being insoluble, falls down as a greenish powder. This, after washing, is employed in printing, after the plan of pigment work, already described. In 1860, Messrs. Calvert, Clift, and Lowe "introduced a most easy and practical method of producing *emeraldine* (a green dye) on cotton fabrics." Dr. C. thus describes his method :—

"The process consists in printing an acid chloride of aniline on a cotton fabric, prepared with chlorate of potass; and, in a few hours, a beautiful bright green gradually appears, which only requires to be washed. If the green fabric is passed through a solution of bichromate of potass, this colour is transformed into a dark indigo blue, called *azurine* [see *ante*, p. 159]. By a modification of the process by persalts of iron, a colour so dark is afforded as to be practically equal to black." Nitrate of copper may be mixed with the hydrochlorate of aniline, without the addition of chlorate of potash, and the mixture printed on the fabric, when gradually a dark green or black is produced. Dark blues, like indigo, may be afforded by a modification of this method. We have a printed specimen of these colours now before us, and the green is so dark as to be scarcely distinguished from black.

It will be thus seen that the present system of calico-printing is characterised by simplicity in its operations, as well as speed; and, in respect to the colour-results obtained, the experience of all our readers will render it unnecessary for us to make any observations. Comparing the methods adopted thirty years ago with those of the present day, it is impossible not to see how great is the advance that has been thus effected. This has chiefly arisen from an extended knowledge of chemical science in the first instance, applied by able men, who associated the science with each operation of their business; and thus conducted it on principles of certainty, instead of empiricism.

At the commencement of the article on practical dyeing, we stated how much it had hitherto depended on empiricism. On the other hand, the art of calico-printing results, in every branch of its operations, upon rigid adherence to rule, system, and science; and, as such, it ranks amongst the most perfect branches of applied science followed by man.

It would be most valuable and instructive if a collection could be formed of printed cotton goods—at least specimens of them—produced during the last eighty years, or rather, perhaps, from 1764 to the present day. We have a pattern of a dress, worn by a relation, and purchased seventy-six years ago. Certainly the fabric is excellent, thick and strong, and the depth of the red dye colour has resisted age, air, light, and washing, for many years. We must admit, that however we may have advanced in beauty of design, colour, etc., it is by no means so certain that permanency has accompanied such qualities.

But, at the time we speak of, the expense of a *good* cotton dress exceeded that at which a good silk one may be obtained at the present. It may amuse our female readers if we relate, that the grandfather of the writer has told him, that he and his wife used to consult, some time previous to the purchase of a new cotton dress, as to whether they could bear the expense, although their means and position fully would warrant such an extravagance. We need not compare processes of those days with the present. Thanks to science, capital, and skill, "*nons avons changé tout cela;*" and our domestic servants can, or do, afford to dress, in our time, in a style that our grandmothers would have been all but shocked at.

It would be interesting, as a matter of inquiry for the political economist, to trace the influence which the arts we have been describing have had on the development of our national progress, and increase of population. The effect of establishing any department of manufacturing operation is quickly that of centralisation. Within the memory of many now living, for example, Manchester and Glasgow, the two great centres of the cotton manufacture, were villages compared to their present extent. It is not only, however, due to the establishment of one branch of manufacture that the material progress of a town or locality is due. For example, a cotton factory is commenced—say in an outlying district—and employs numerous hands. They, from the early hour at which they commence work, must live close to the factory; hence start up house after house, until a village is formed. But the wants of that factory lie also in machinery, either in respect to its repairs or extension; and, consequently, machine-shops are commenced, which employ another and

numerous class of hands. All these have to be fed; and, therefore, shops and extensive retail trade progress. The immense quantity of goods that enter and leave such places require a railway; and hence a new source of local employment. Our trade, however, is one of great export, and thus shipping must be built, docked, etc.; resulting in the establishment, on a neighbouring stream, of works for such purposes. Dye and print-works are added; and gradually the population becomes greatly increased—added to, still further, by the erection of chemical works, to supply the necessities of the dyers, bleachers, and calico-printers. In fine, the village becomes a town, radiating prosperity in all directions; and, step by step, its influence extends far beyond its own locality, becoming of national importance. But it does not rest here. In foreign lands its productions become known, with which its name is identified; and so, from small beginnings, the greatest commercial, social, national, and political results flow.

Such is a bird's-eye view of the history of Manchester, Bolton, Oldham, Blackburn, Bury, Wigan, Ashton, etc.; and, in Scotland, of Glasgow, and neighbouring townships. Although comparatively young, we have watched, for the last quarter of a century, a large proportion of this extension in the places named. Barren heaths, moors, and marshes have become, in that short space of time, scenes of the greatest commercial activity. Waste countries, that human foot scarcely trod, and beautiful vales that were but occasionally visited by the tourist, now teem with the smoke of the factory, or the steam of the locomotive; and thus a commercial prosperity has been engendered amongst us, that makes us the warehouse of the world.

This work is not the place for discussing the moral effect that the arts we have now been describing have had on the population of the districts which have been alluded to. According to theological teaching, sin came into the world by the agency of two persons; and we cannot suppose that two millions, more or less congregated together, will be much better than their first parents, save by influences of a Higher nature, that we shall not even name, but which the moral sentiments of our readers will at once suggest. In a mental or educational point of view we may speak, because, to a certain extent, we have been permitted to take a humble part in such questions. We have seen much of the working of the factory system—not the legal, but the internal and social form of it; and we have come to the conclusion that, like the regular drill of the soldier, the demands for system and order inside of the factory, very considerably exert their influence in the homes of the operatives. Many of them are pictures of neatness and propriety, and would do credit to persons in a much higher sphere of society than those who occupy them. In most of the large manufacturing districts, the masters take an active interest in the welfare of the workmen; for, if they had no motive but that of personal and pecuniary interest, that would be sufficient to urge them to look after the health and general welfare of those employed; all the profit of the master depending entirely on the punctual attendance of the man at his work. Frequently, schools, means of recreation, lectures, etc., are provided for their benefit; and we have personally addressed thousands of these work-people on scientific subjects, that have been listened to with an attention and intelligence not to be found in an audience of "respectable" pretensions. Much remains, doubtless, to be done in raising our workpeople to the moral and mental standard they should occupy; but we are highly encouraged for the future by what we have already seen effected; and believe that, with the agencies now at work in these respects, after a lapse of a few years, little will remain to be materially improved, so far as exteral human agency can be effective.

CHAPTER III.

ELECTRICITY AND ITS APPLICATIONS.

ELEMENTARY PRINCIPLES; ELECTRICAL APPARATUS, ETC.

AS this work may have amongst its readers a large proportion who have little acquaintance with the science of electricity, it will be desirable that we should devote some space to a popular description of elementary principles. We may consider electricity to be divided into three great branches—viz., Frictional, Chemical, or Voltaic, and Magnetic. It is only with the first that we have here to deal; and it will be sufficient, for the present, to say that voltaic electricity is that branch of the science, with certain of its applications, that depends on chemical action for the development of electric force; whilst, as the name indicates, electricity produced by magnetism is the result of magnetic induction, which, under certain circumstances, develops electricity, light, heat, and chemical action. Midway between frictional, voltaic, and magnetically-induced electricity, is that afforded by the induction coil, of which Rhumkorf's is the type, and by means of which a kind of mixed results is obtained; the effects produced by such instruments resembling those afforded by the electrical machine, the voltaic battery, and magneto-electric induction.

If a dry glass surface, as a tube, be rubbed by a dry silk handkerchief or a piece of dry flannel, what is called electrical excitation takes place; by which is meant that the glass surface (apparently) acquires new properties. For example, if a few small pieces of paper or light feathers be placed on an ordinary table, and the rubbed glass surface be brought near to them, they will start upwards, and, for a time, adhere to the surface of the glass.

By the trial of this simple experiment a leading property of electricity becomes at once apparent. The property here referred to is that of *attraction*; for it is evident that the excited surface of the glass has the power of drawing the feathers to it, and of causing them to adhere for some time.

Not only glass, but a great variety of other substances are capable of electrical excitement by friction. It is not here the place to enter into a discussion as to whether all bodies may not be so excited; but, for the present, we content ourselves by stating, that amber, resins of most kinds, consequently sealing-wax; also sulphur, hair, especially that of the human subject and the cat; common paper, silk, water, as just condensing from the state of vapour—all these, and many others, may be made electrical by friction. Gutta-percha, and some forms of india-rubber, may be specially named amongst such bodies, and, as we shall subsequently see, may be substituted for glass in the construction of frictional electrical machines.

But just as the two poles of a bar magnet or the needle of the compass have opposite properties, so the electricity excited by the friction of glass and that of resins, &c., are opposed, in some respects, to each other. For the sake of simplicity, we shall confine our remarks, at present, only to the phenomena developed by glass and sealing-wax, because these familiar objects afford a ready means for the most unscientific reader to pursue experimentally, with our written description, an inquiry into some most interesting facts of the science.

If a piece of sealing-wax be rubbed with dry flannel, and then be presented to the pieces of paper, or feathers, precisely the same results will be manifested as are afforded by the rubbed glass. But a step further leads us to discover other electrical facts besides attraction. These are, that the force has a repellent as well as an attractive power; and, still further, that it possesses a kind of double nature.

Resuming for a moment our illustration of the magnetic needle, as being analogous, in certain respects, to that of an electrified body, we may remark, that when the north poles of two magnets are presented to each they are mutually *repelled*. The same is equally true in regard to two south poles. But if a north pole be presented to a south, or *vice versâ*, then poles of different denominations *attract* each other. Now precisely the same result occurs in respect to bodies electrified by the friction of glass and resin. If two feathers be both electrified by the force as obtained from the friction of glass, they will repel each; and if two feathers be similarly presented to each, first being each electrified by rubbed sealing-wax, they will also repel each other. But if a glass-electrised feather be presented to a sealing-wax electrised feather, the two feathers will attract each other; hence arise the distinctive terms applied to

each kind of electricity—*Vitreous*, or glass-excited electricity, and *Resinous*, or resin-produced electricity; that is, by the friction of the respective substances.

But, for reasons that will subsequently be more fully explained, other terms have been assigned to these separate forms of the force. They are *positive* and *negative;* the former taking the place of the term vitreous, and the latter that of resinous. With this explanation, we shall, in future, use the words *positive* and *negative* in the place of those first explained.

So far we have seen that electricity possesses both an *attractive* and *repulsive* force; and that it is also capable of presenting itself in a twofold form. Here may be briefly explained, that, at one time, it was considered that the difference between positive and negative was simply due to the presence or absence of free electricity, represented respectively by the signs + or —, two that convey, algebraically, the same meaning as positive and negative. This formed the chief feature of what is called the single theory. But, at the present day, it is believed that electricity is of a twofold and opposite character, analogous to magnetism; and, in some respects, bearing resemblance to the compound nature of white light.

We next turn to another quality or property of electricity, and of matter generally: it is that of *conduction.* At one time, all bodies, in relation to both heat and electricity, were termed conductors and non-conductors absolutely; but experience taught that this distinction is relative, and not absolute. For example, glass conducts heat badly; but still we all know that heat will at last find a passage through it: air is a still worse conductor than glass, yet it will conduct heat. Precisely the same thing occurs in regard to electricity. At one time, bodies capable of producing electricity by friction, were called, indifferently, non-conductors, or *electrics;* whilst those which could not be so excited, were termed *non-electrics*, or conductors. The reason of these terms being, like positive and negative, relative rather than absolute, will appear as we proceed.

By electric conduction we mean the quality or power any body possesses of allowing of the transmission of electric force, or, as it is popularly termed, yet erroneously, the electric fluid. But, after all, despite the great advance that has been made of late years in the science, we are yet quite uncertain as to the nature of the process by which an electric excitation propagates its effects, by conduction, between its origin and point of action. In our future pages we shall have to discuss such questions; and refrain, therefore, from doing so here, because our present duty is simply to point out only the elementary principles of the science. To simplify this difficult question, we shall, for our present purpose, assume that electricity travels something after the same manner as gas or water does from the works to the place of use—an assumption which, although far from correct, will in nowise invalidate any conclusions that we may arrive at.

The best conductors of electricity are the metals; but these vary, *inter se*, to a very large extent. Silver and copper, for example, are excellent conductors of electricity; and the latter metal, and its alloy, brass, are exclusively used in the construction of instruments intended to show the phenomena. Iron wire is employed for telegraphic purposes on land, because of its cheapness; for although it is a far worse conductor of electricity than copper, still, by using wires of large dimensions in respect to thickness, the difference is, to a large extent, compensated for.

Charcoal made from some kinds of wood; coke, especially the compact kind used for iron-smelting and in locomotives; plumbago, or black-lead, in solid masses, which is another form of carbon—are all conductors not very greatly inferior to metals. Liquids are conductors, but to an immensely diminished extent below the metals; concentrated and dilute acids, with saline solutions, being the best of liquid conductors. Heated air and vapour are also, but to a moderate extent, conductors; whilst dry air—that is, air destitute of moisture—is, perhaps, one of the worst conductors of electricity with which we are acquainted. It hence happens, that to attempt electrical experiments in damp weather, is almost sure to be attended by failure; whilst, in dry air, the success is, with moderate caution, certain, and attended with brilliant results. We have seen a machine that, during a dry east wind, would afford a spark of two feet in length, incapable of producing one of two inches in wet weather, with a south-west wind prevalent. The electrician is at all times as careful as possible to keep all parts of frictional electrical apparatus free from moisture; for otherwise it is impossible to conduct experiments with the most remote chance of anything like adequate results.

The art of *insulating* a body electrically, and, consequently, of producing what electricians term *insulation* is a result of the application of the laws thus briefly described. Without entering into any particular description of any form of electrical apparatus, we may state that, generally, it is essential that an electrified body should be kept away from conducting bodies in various investigations or experiments; hence the conductor of an electrical machine is mounted

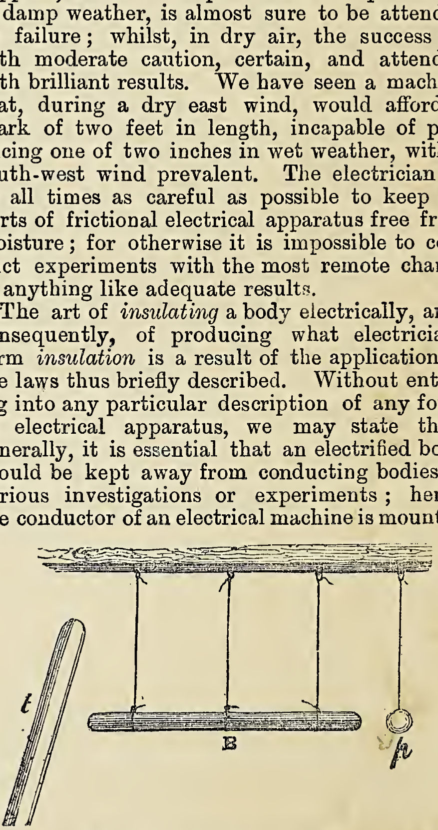


Fig. 91.—Electric Insulation.

on a glass rod, which insulates it from conductors that would immediately convey the electricity away unperceived. Silk threads, glass pillars,

plates of gutta-percha, resin, ebonite (a species of india-rubber), &c., are all of constant use to insulate an electrified body. In the preceding cut, the uses of conductors and non-conductors, or insulators, are illustrated. The three threads support a brass rod, B; *p* is a pith ball, suspended by a thread, and kept to the extent of about an inch from B; *t* is the glass tube already mentioned as capable of producing free electricity if rubbed by a dry silk handkerchief. Now, if the excited tube be held near the brass rod, B, the electricity will be *conducted* along the rod, which is *insulated* by the three silk threads, and *attract* the pith ball, *p*; hence, by this simple apparatus, electrical *conduction*, *insulation*, and *attraction* are simultaneously exhibited.

If a break occurs in the continuity of a conductor, and the free electricity be highly developed, then the force will leap, apparently, over the obstruction, if the interval be not too far apart. To illustrate this, many forms of electrical apparatus have been made; but a familiar instance is found in nature. Supposing, for example (continuing to use popular phraseology), any conducting object, as a lightning conductor, be "struck" by the "electric fluid," the interval between the cloud and the stricken object will be illuminated by a brilliant flash: but this instantly ceases when the electric conduction is made continuous by the metal of the conductor; hence the use of the latter, in the shape of metallic rods, as attached to tall chimneys, columns, steeples, the masts of ships, and other objects reaching upwards from the surface of the earth. Vulgarly they are supposed to "attract" the lightning; but their office is just analogous to that of gas and water-pipes; that is, they simply serve as means of conveying or conducting the force.

Here we may cursorily notice why destruction of houses, &c., occurs, although some slight apparent protection be afforded in the metallic arrangements of the building. Supposing the electric force "enter" by the chimney, the soot of which is a partial conductor; next comes the iron grate, which is an excellent conductor. Perhaps in the room will be a bell-wire reaching over the house in its extension to other apartments. Now the wire is of itself, most probably, far too thin to convey the great amount of electric force prevalent at the moment: hence the electricity seizes, as it were, on all metallic objects in the entire building; consequently they are all called upon to take a share in conveying away the force. But between them are intervals occupied by bad, or, comparatively, non-conducting bodies. These will suffer; for the electric force will, owing to the resistance to its passage, either break them to pieces or set them on fire. In our subsequent pages we shall cite several experiments that may be tried by electrical apparatus, producing precisely the same effects on the small scale as we notice in the large and terrific forms in nature; for it is quite within the power of man to call out, by his instruments, sufficient of electricity from the bodies that surround us, as even to produce the most fatal and destructive effects, in his laboratory, by that which causes the same in the great laboratory of nature.

And here we may notice the universality of electric force in its active or quiescent state in nature. There is every reason to believe that, besides the lightning, other meteorological phenomena are also due to electricity—such as hail, rain, snow, the aurora borealis, &c.; or, if not due exactly to it as their cause, are still simultaneously attended by its free presence. Descending to the regions of the earth, we can, experimentally, prove free electricity to be present in, and active on, the bodies of animals; and, most probably, in and on plants. In the bowels of the earth, there is little doubt that, in most cases, the formation of metallic veins and minerals is in part, and occasionally entirely, due to electrical action. In respect to its presence in metallic veins, that has been frequently proved by experiment; and equally so have, on the small scale, minerals been produced in the laboratory by slow electric action; such products having been exactly like those found in nature.

Lastly, in this brief summary of some of the leading elementary principles of frictional electricity, must be noticed what is called *Induction*. The investigation of this subject occupied a large portion of Faraday's life; and, even yet, its full extent and definition have to be arrived at; hence to attempt a popular exposition of it is difficult. Of course we shall have to deal with it extensively hereafter. Here we may shortly illustrate its nature as follows:—

As being extremely simple in repetition by any one, we shall suggest the following experiment, illustrating magnetic induction as facilitating the understanding of electric induction. If a common horse-shoe magnet be applied to a steel needle, one pole to one end, and the other pole to the other extremity of the needle by rubbing it; then if the needle be suspended by a thread, so that it can turn freely, one end will point a little to the west of the pole star in the heavens, and the other, of course, to the south-east. Now it will be found that the end which points *southward* is that which has been rubbed by the north or marked end of the horse-shoe magnet, whilst that which has been rubbed with the south pole of the magnet will point to the north. It is evident, therefore, that the magnet has produced a definite and new effect in the steel needle; and this is done by virtue of the *inducing* or *inductive* power of the magnetism in the horse-shoe magnet: hence the substantive *induction*, expressing the power and result.

Now we have here also used the word *pole*. This is generally applied to that manifestation of force that is evidenced at the extremity of an excited body; hence the *magnetic poles* of the needle or of the earth, and the *poles* or extremities of the wires of a voltaic battery. But the term *polar* has a more extended meaning in science. It is applied when either the particles or "molecules" of matter are rearranged by the action of a force, so as to

point or move in directions definite, but different from what previously existed; or when even the force itself undergoes such a modification. An instance of the latter is found in the polarisation of light, wherein, by reflection or refraction, a ray acquires new properties that are polar in their character.

Applying the same principles to electric induction, we may explain, that when an electrically-excited body—as the glass tube or sealing-wax already instanced—becomes so, it immediately *induces* a polar state in all near objects. For example, we may suppose the *natural* condition of the latter—that is, when they are under no influence of electricity—to be represented as follows:—

pn, pn, pn, pn.

In which we suppose the positive *(p)* and negative *(n)* condition to be perfectly undiscernible, as is always the case in an unexcited body. But we present the excited glass rod, *G*, and the following changes take place:—

Gp, np, np, np.

Wherein we suppose that *Gp* represents the positive glass, inducing a re-arrangement of the electrical conditions, represented by the new arrangement of the letters. If, on the other hand, the excited sealing-wax, *W*, be used, affording negative electricity, we should have—

Wn, pn, pn, pn.

The following diagram illustrates precisely the same thing, but more perceptibly to the eye. It supposes that two cylindrical bars of brass are mounted on glass legs, to insulate them. Either cylinder may be supposed to be excited,

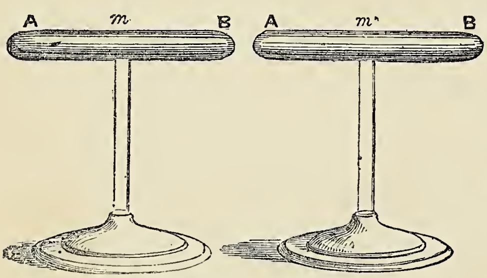


Fig. 92.—Electrical Induction.

when the polar arrangements are at once shown by the letters A and B; the letters *m m'* pointing out a middle position, wherein electrical excitement, or polarity, is absent. The mechanical effects of the attraction caused by their induction is shown by the following cut, in which the tendency of the last pith ball to touch the other at the adjacent extremities of the two cylinders is represented.

We have thus endeavoured to point out, for the benefit of those who are strangers to electricity, the general meaning of such terms as *electrical excitation, conductors, non-conductors, electrics, non-electrics, insulation, negative and positive, induction,* &c. It is a great fault of many scientific works, that the unpractised reader is suddenly plunged into a maze of phrases, the meaning of which he neither under-

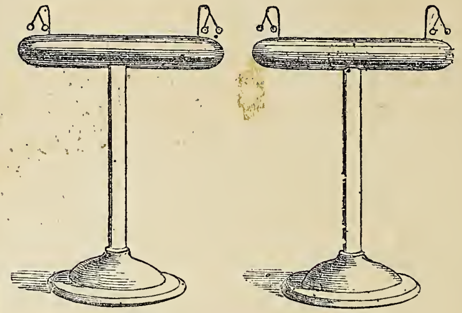


Fig. 93.—Electrical Induction.

stands, nor can he find in any ordinary dictionary. It is true that we might have reserved these explanatory remarks until we arrived at the separate discussion of each of the matters already named; but the preceding observations, whilst giving a general view of the chief subjects of electrical science, and the leading peculiarities of its phraseology, will save a vast amount of circumlocution, and put the unscientific reader, who has carefully perused them, in as good a position, so far, as old followers of science.

ELECTRICAL APPARATUS.

The electrician, equally with the chemist, requires apparatus, by the use of which he can carry on his experimental illustrations, or pursue fresh fields of investigation; and it will be, therefore, advisable that we should devote some space to the description of the most requisite of electrical instruments, the principles of their construction and use, and the best mode of adapting them to special purposes.

Modern science has advanced equally as much by the construction of improved forms of apparatus as by any other means. A century ago, every branch of science suffered from the imperfection of instruments of research. We are almost ashamed to say, in the cause of science, that the parallax of the sun was so defectively observed, that, since the year 1860 or 1862, rectifications have had to be made, which greatly affect our estimate of the distance of that luminary, and also of the speed of light to the earth. The assigned error, in the first instance, is not less than 3,000,000 miles; and, in the latter—that is, the consequent rate of the speed of light emanating from a heavenly body, and arriving at the earth—has been also considerably over-estimated.

Hence arises the necessity of improving our scientific apparatus to the utmost possible extent; and the sequence of this is discovered in the more exact measurement of all natural phenomena. In the early history of electricity and magnetism, errors of great magnitude constantly

occurred, that gave rise to the crudest kind of theories: and no branch of science has been free from that reproach. We even yet await great mechanical improvements in the construction of our apparatus; and, awaiting that, many most interesting problems of philosophy, observative and experimental, remain unsolved.

The simplest form or manner by which we can evolve the phenomena of frictional electricity, has been already hinted at, but may now more properly be specially detailed. We have shown that a glass tube, rubbed by means of a dry silk handkerchief, flannel, &c., and sealing-wax similarly treated, evince the phenomena of electrical attraction, repulsion, &c. A sheet of foolscap paper, carefully dried, and well rubbed by india-rubber whilst resting on the surface of an ordinary wooden table, becomes, in dry weather, highly charged with free electricity; not only showing the effects of electrical attraction on presenting the knuckle of the hand to its rubbed surface, but also affording, in the dark, sparks indicating free electricity, and illustrating, on the small scale, precisely the same phenomena as are observed in the thunder-storm. One of the most readily excited surfaces, when a dry east wind is prevalent, is the fur of a black cat, rubbed by the dry hand or a silk handkerchief, from the head to the tail. And this simple means produces evidence of electrical attraction, repulsion, and the spark. Indeed, under exceedingly favourable circumstances, we have succeeded in charging a small Leyden jar (to be subsequently described) by such means.

Of course, for elementary illustration of the most simple character, these methods may be adopted; but for the object of philosophical investigation they are valueless. Hence the construction of electrical machines of various kinds, by means of which a large amount of free electricity can be generated.

The first form of electrical machine was that suggested by Hawksbee; in which a glass globe, caused to rotate by a handle against a rubbing surface, took the place of the elementary rubbed-glass tube. This, doubtless, was the initiative of the cylindrical electrical machine that succeeded the glass globe form. We remember having seen a specimen of the latter, in a very aged form, some thirty years ago; but these kinds of electrical machine are now completely obsolete, as the cylindrical, in fact, is rapidly becoming.

These are manufactured in great variety: a common form is that represented in the annexed cut. *a b* represent the glass cylinder, which is blown with two necks, that are placed, by brass cups and spindles, in two bearings; each of these being supported on glass legs, *c d*. A winch handle, *e f*, turns the cylinder on its axis from left to right; *g* is the rubber, by means of which the *cylinder*, *a b*, is excited; *m* and *n* represent an arrangement by means of which the *rubber* can be approximated or removed from the cylinder, *a b*, so as to increase or diminish the pressure on its surface: *h* is what is called the *prime conductor*. It is fitted, at the end nearest the cylinder, with a bar armed with pointed wires, so that the latter may collect the free electricity from the surface of the revolving cylinder, after the latter has been excited by the friction of the rubber. *i* and *k* respectively represent the insulating glass rods (see *ante*, p. 176). by means of which all electrical communication or conduction is prevented, between the rubber, cylinder, and conductor, with the stand of the machine, and, consequently, with the earth or any other large conducting body apart from the machine.

In using this machine, the rubber, *g*, is connected by a chain, fixed on a knob at the back of the rubber (as shown in the engraving), with the earth, or, still better, with a gas or water-pipe. But a copper wire is far better than a chain in all electrical experiments wherein its use is possible, simply because its conducting power is continuous; whilst that of the chain, from the very nature of its mechanical construction, is subject to breaks. We never use a chain under any circumstances; but, in most works on electricity, that is recommended. Before using such a machine, or, indeed, any kind of frictional electrical apparatus, all should be heated *slightly*, but not too much beyond the temperature of the room in which they are to be used; because otherwise—that is, if they be of less temperature—the moisture of the atmosphere will condense on every surface, and afford a conducting medium that will almost destroy every chance of success in experimenting (see *ante*, p. 176). For precisely similar reasons, all dust must be carefully removed; and both of these operations are best performed by using an old *dry* silk handkerchief: cotton or linen cloths, with flannel, are of little use; for almost in all cases they leave fibres on the surface of the apparatus, that too effectually dissipate free electricity.

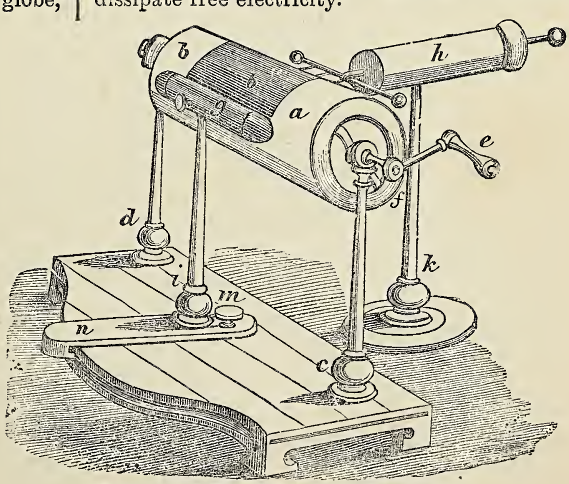


Fig. 94.—Cylinder Electrical Machine.

Nothing is so essential, in frictional electrical experiments, as *perfect* cleanliness. We have

seen some of the most eminent philosophers of our day, not excepting Faraday, fail through an accidental neglect on the part of assistants, in respect to preventing moisture, dust, and dirt resting on any portion of the apparatus employed. Free electricity, developed by friction, like the riches spoken of by one of old, "taketh unto itself wings and flyeth away." The most powerful apparatus for illustrating intense electricity that has ever been constructed, was the hydro-electric machine, formerly in the Polytechnic Institution, Regent Street, London. We have had this in use for six months together, twice daily, and could tell the state of the weather, in regard to moisture, at the first lecture experiment, equally as well as by consulting the hygrometer. Its particular description will be given hereafter ; suffice it for the present to say, that whilst, with a dry east wind, the spark it afforded was at least an inch wide, and, occasionally, two feet long, showing precisely the same appearance as a flash of lightning in all respects ; in a moist south-west wind, it required all possible care to conduct even the ordinary electrical class experiments. How much more so, then, is requisite every possible care in managing small electrical apparatus.

The preceding, and, for the present, future remarks, are solely applicable where glass is the surface that, by friction, is employed to afford free electricity ; and our remarks are equally directed to the cylindrical machine as to the plate instrument yet to be described, in regard to the preparation of the instruments for experimental purposes.

Every part, rubber, legs, conductor, &c., having been perfectly cleared of dust and moisture, the rubber is to be coated with an amalgam, made by pounding together, in a mortar, an ounce of *clean* zinc shavings with two ounces of mercury. This amalgam, as it is called, is always better when freshly prepared ; but still it may be kept for some time uninjured by putting it into an accurately-stoppered bottle. The great point is to prevent access of atmospheric air, beccause the oxygen of the latter would unite with the metals to produce their oxide—a result that greatly militates against the utility of the amalgam. The latter, when required for use, is to be mixed with just as much softened or partially melted tallow, of the *best kind* and *free from salt*, as will make a paste ; and this is to be applied to the surface of the rubber.

In both the cylindrical and plate machine a silk flap is placed on the rubber, which extends so as to cover the greater portion of the glass intervening between the rubber and the conductor. The flap is indicated in the preceding cut by the dark portion intervening between the two ends of the cylinder. A careless electrician allows this to get dirty by contact with the greasy matter that passes on turning either the cylinder or plate after the amalgam has been placed on the rubber. This should never be done. After applying the amalgam to the rubber, the latter should be so adjusted by the usual arrangement as to press gently, but evenly, on the cylinder or plate. Either is then to be turned round ; and so long as any appearance of grease rests on the glass, it should be rubbed off. So soon as the greasy appearance is removed, the silk flaps, or covers, may be placed on the cylinder or plate, which should then be in complete order, external circumstances being favourable for experimental purposes.

But despite all the precautions we have named, and many others we could and may suggest, there seems at times, in the ordinary glass machine, a "perversity," if we may so say, that, at first sight, appears not to be conquered. But this is an error. Nature never can be wrong ; but man may be. If the glass cylinder, or plate, contain much soda as a constituent of the glass, it will always be greasy, and never work well ; and hence the necessity of choosing the best glass for an electrical machine. But, even supposing this to be obtained, failure may yet arise. In such cases our resource has always been to wash every part of the apparatus with *warm* spirits of wine, by means of a sponge. This cannot permanently *wet* any part, nor leave moisture, because the alcohol is volatile, and has also a great attraction for any water, and a solvent action on grease and dirt that may exist on any apparatus employed in experiments in frictional electricity. This, attended with the use of the different precautions already named, can scarcely fail to bring all the apparatus into the best of order, unless the experiments are conducted in a damp room, or even in a dry one where the atmosphere is saturated with moisture. Under the latter circumstance, no man of the least experience in electrical science would attempt to perform an experiment ; although, by the way, we once saw a "professor of natural philosophy," in a college lecture-room, with a sink and running water behind him, on a wet night, *try* to lecture (so far as experiment went) ; but need scarcely say that he could not exhibit one experiment.

We fear that it would be too tedious to the majority of our readers to pursue this subject further, and believe that we have, at all events, stated the most important points that require attention. We shall, therefore, leave to the common sense of experimenters the duty of putting into practice what we have urged.

It is evident that the very form of the cylindrical electrical machine must militate against its being an apparatus capable of producing, except when of enormous size, any large amount of free electricity, even under the most favourable circumstances. Only the external surface can be rubbed, and that occupies a large amount of space. The plate machine, on the contrary, can be made capable of producing a much larger amount of free electricity, for both its surfaces may be rubbed simultaneously ; and even a double pair of rubbers may be employed.

The ordinary, and, to our view, the best form of the glass plate machine is that in which only one pair of rubbers is used ; and this plan is generally adopted in the construction of large machines. The ten-feet plate machine, formerly at the Panopticon, London, was furnished with

two pairs of rubbers; whilst one of a seven-feet plate, at the Polytechnic, Regent Street, London, had but one pair. With either of these machines, owing to the great surface of plate for friction, some magnificent electrical effects have been produced.

In plate machines with single rubbers, the rubber is placed at one side or end, with a silk flap attached, to cover the plate until nearly at the opposite side, where the conductor is placed. Of course, both the rubber and prime conductor are insulated by glass legs, which are greatly improved by varnishing them over with a solution of shell-lac in spirits of wine; for such a varnish prevents, to a considerable extent, the deposition of moisture on their surface. Legs of gutta-percha or ebonite are also excellent insulators, and have the advantage of never allowing the deposition of moisture on their surface under all ordinary circumstances.

The following engraving illustrates a good form of plate machine, where the size of the plate of glass is, or exceeds, two feet in diameter. It is supposed to be fitted with two rubbers, *a a*, from which extend the silk flaps, *b b*. At *c c* are the pointed ends of the prime conductor, *d*, to which they are attached by two brass arms, *e e*. The handle, by which the plate is caused to rotate, is shown at *f*. The construction of the rest of the machine requires no further explanation.

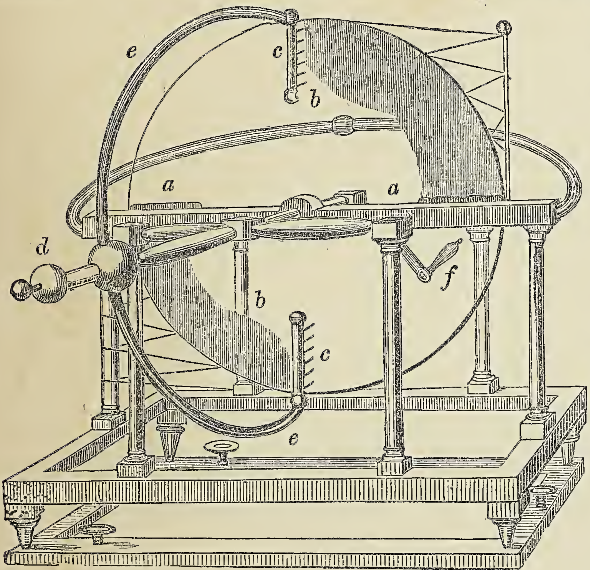


Fig. 95.—Plate Machine.

A great difficulty in making a glass plate machine with two rubbers work well, is in adjusting the pressure so that each pair of rubbers shall act with equal force on the plate. If one exceed the other in this respect, there is great danger of breaking the plate at the point where its axis or spindle is fixed—an accident that occurred, within our experience, three times with a three-feet plate, and that induced us to convert the machine into one with but one pair of rubbers and one conductor. A loss of power from the use of only one rubber, is nearly made up by giving the plate a few extra turns per minute, and all risk of breaking the plate by uneven pressure is avoided.

Small machines are constructed in a somewhat different form; and the following cut

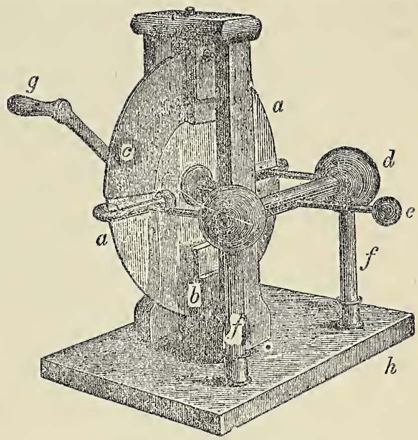


Fig. 96.—Plate Machine.

illustrates such as are usually sold by the instrument-makers, when the diameter of the plate runs from nine to sixteen inches. *a* represents the glass plate, and *b b* are the rubbers; *c* is the flap of silk extending from the rubber nearly to the conductor, *d*, from which arms extend, with pointed ends, to the plate, as in all other forms of the electrical machine: *e* is the brass knob of the conductor, whence the sparks are taken; and the conductor is supported on two insulating glass legs, *f f*; the handle, *g*, turns the plate; the whole machine resting on a broad mahogany slab, *h*.

This form of the machine answers very well for elementary purposes; but it has the objection of not having the rubbers insulated. In the absence of this arrangement, although all the phenomena of positive electricity, as developed at the conductor, may be exhibited, those as evidenced at the rubbers cannot be observed. When in use, the plate, like the cylindrical machine, must have its rubber connected with the earth, or, still better, a gas or water-pipe, to afford a continuity of electrical conduction. In this, and other respects, the instructions given for cleaning, preparing, amalgating, &c., at p. 180, *ante*, are equally applicable to the plate machine.

Other forms of the plate machine have been proposed, the differences being, however, chiefly of a mechanical character, except in the case of that proposed by Mr. Woodward, in which two plates, and, of course, two sets of rubbers, &c.,

are used. In fact, this double plate machine consists simply of two machines arranged as one. It never came, however, into general use, for a variety of reasons that need not here be mentioned.

One of the greatest improvements that has yet been effected in the construction of electrical machines, is that invented, some years ago, by Carl Winter, of Vienna, and introduced into this country, in 1857, by Dr. Ferguson, of Edinburgh. One, constructed at Vienna, with a plate five feet in diameter, for the Polytechnic school of that city, gave sparks *four* feet long!—an enormous length, and far exceeding the results afforded by the ten-feet glass plate machine, formerly at the Panopticon (see *ante*, p. 180), or the seven-feet plate machine of the London Polytechnic Institution, or the hydro-electric machine, formerly in the latter establishment. From the two last-named instruments, under the most favourable circumstances, we never succeeded in obtaining a spark more than two feet long, and then only in the instance of the hydro-electric, which will be presently described, and that was more powerful than the plate machine when east and dry frosty winds had been for some time prevalent.

Although ebonite, gutta-percha, or vulcanite, may be employed to construct one of these machines, still it is not any superiority on their part over glass that renders this instrument so powerful; for we have seen an ordinary plate machine have its length of sparks trebled and quadrupled by the singular addition to the conductor suggested by Carl Winter. Still, all forms of electrical machines are essentially improved by the use of either of the first-named substances, in place of glass, in making the legs or supports.

One of the simplest, cheapest, and, for its size, an effective machine, is that which the inventor, Mr. Simmonds, showed us some years ago. The form of construction is, in all respects, precisely the same as the double rubber, small, vertically-arranged plate machine, illustrated, at p. 181, by Fig. 96. The difference between his instrument and the ordinary plate is, that the plate he used was composed of a mixture of two parts of gutta-percha melted with one part of ordinary resin. The mixture is rolled out on a slab, and rounded so as to form a plate like the usual one of glass. The rubbers he employed were made of rabbit-skin, stuffed so as to form a soft cushion, the hair of the rabbit being pressed against the plate. The insulating legs were made of the same material as the plate. By a little ingenuity, and copying the ordinary form of plate machine, any one may construct a twelve or fifteen-inch, or, indeed, any other size, for a few shillings, all the materials being cheap, and the greater portion only requiring to be moulded, cut, or pressed. Ebonite, or vulcanite, may be used in a precisely similar way; and affords excellent results as a plate machine, and for insulation, as already pointed out.

From what has been already stated, it is evident that a large range of substances can be made to afford electricity by friction. As we shall see hereafter, even water may, under certain circumstances, be made an excellent electric. The student has only to bear in mind the general law of electrical excitation—viz., that good conductors are bad electrics, and *vice versâ*, to have at all times a general guide in regard to the construction of all kinds of electrical apparatus, and their general management, to procure successful results in his experiments.

The *Electrophorus* is another and very simple arrangement, by means of which free electricity can be readily generated for a variety of purposes. The best form that we have yet seen is that in which the *sole* (presently to be described) is of ebonite, or vulcanite; and an electrophorus of this kind is sold by most instrument-makers at a moderate price. It was invented by the celebrated Volta, and a cheap kind may be made as follows:—The sole is made by filling a tray of tin plate, of a circular form (say fifteen inches in diameter, and half an inch deep), with a mixture of equal parts of shell-lac, resin, and the best turpentine, that are to be melted together with careful stirring. This mixture is to be poured into the tin tray; and, when cold, this altogether forms the *sole* of the instrument above referred to as occasionally, with advantage, made of ebonite. Even a circular plate of gutta-percha answers equally well with the preceding; and, as it may be readily cut to the required circular form, perhaps it is about the readiest and cheapest kind of sole for the electrophorus. Next, a circular plate of copper, zinc, or tin (of which the first is best), should be cut: the thickness is not important, but its diameter should be two inches *less* than that of the sole. This forms the *cover*, and to it must be attached a piece of glass rod, gutta-percha tube, or ebonite, to form a *handle*. The following cut represents each part described, A being the resinous sole, C the metallic cover, and B the insulating handle.

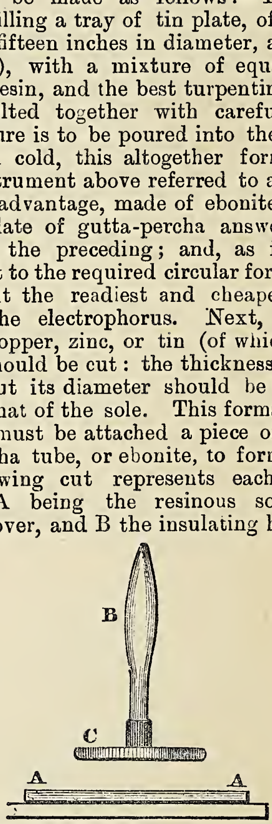


Fig. 97.—The Electrophorus.

The method of developing free electricity by this simple apparatus is as follows:—Rub, with a kind of slipping sort of motion, the sole by means of dry soft flannel or fine fur (using the hairy side next to the sole in the latter case). After repeating this occasionally, the sole becomes excited. In damp weather it is best slightly to warm the sole, cover, flannel, etc., to dispel adherent moisture. By the friction of the plate on the resinous surface, negative or resinous electricity is produced (see *ante*, p. 175). Next lay the cover (holding it by its

insulating handle) on the surface of the excited plate, and touch the top of the cover by the finger of the other hand. Now raise the cover to some distance from the sole, and then present a brass knob, when a spark will pass, evidencing the presence of positive or vitreous electricity. Without freshly exciting the resinous plate, a constant supply of positive electricity may be obtained for some time by again simply placing the plate on the sole, touching it with the finger, and raising it. Thus by one excitation the electrophorus may be kept for a considerable time in action. We had one, some years ago, that retained its power for twenty-four hours in dry weather. It is advisable to have the rim or edge of the cover carefully rounded, or turned up, so as to present no rough or pointed surface; and if a brass ball be attached to it vertically, by a wire rising an inch high from the cover near its edge, the spark can be much better drawn, and the electricity communicated to a Leyden jar or other apparatus. An electrophorus, made of a gutta-percha sole, a zinc cover, with a piece of gutta-percha tube for a handle, and the wire, with the ball, may be constructed at a cost of less than 5*s.*; and if the gutta-percha sole be eighteen inches in diameter, and the cover about fifteen inches, sparks may be obtained, under ordinary circumstances, in rapid succession. Absence of dust, dirt, and moisture is as essential in using the electrophorus as with any other electrical instrument.

We may here briefly explain how it is that the electrophorus affords free positive and negative electricity. As previously remarked, the resinous surface becomes negatively electrified. When the cover is placed on it, a thin film of air subsists between the resin and the metallic plate; and, to a certain extent, the film answers the same end as the glass of the Leyden jar, subsequently to be described. The wider part of the cover becomes, by induction, vitreously or positively electrified; and on touching the cover with the finger, the electrical equilibrium is restored. But on removing the finger, and raising the cover from the sole, the cover again, by induction (see *ante*, p. 177), becomes positively electrified; and, consequently, on being removed away, gives a spark of positive or vitreous electricity.

The hydro-electric machine, although not giving the length of spark described at p. 182, *ante*, as obtainable from Winter's plate arrangement, affords an enormous quantity of electricity that will enable the experimenter to produce the most brilliant results in respect to light, heat, and mechanical force, that can be artificially produced by any means of exciting frictional electricity. At least, we refer to that which was constructed for the Polytechnic Institution, London; and which, some years ago, we had in daily use for months together. As it was the largest that has yet been constructed, and as it was the first, we shall describe it as the type of all other and smaller machines. But, before doing so, it may be interesting to trace the history of the important discovery resulting from the friction of moist steam.

It was first made, about thirty years ago, by Mr. H. G. Armstrong, of Newcastle-on-Tyne, at Seghill, by observing the escape of steam from an ordinary boiler, respecting which there was not the least peculiarity as regards construction; and the discovery was accidental. It must be premised that a leak had occurred between a small cylinder on the surface of the boiler and the body of the boiler itself; and the leak had been temporarily stopped by putty and tow. Mr. Armstrong then relates how the discovery took place. "The steam began [again] to escape at the joining through a fissure in the cement, and has ever since continued to issue from the aperture in a copious horizontal jet. Soon after this took place, the engine-man having one of his hands immersed in the issuing steam, presented the other to the lever of the safety-valve, with the view of adjusting the weight, when he was greatly surprised by the appearance of a brilliant spark which passed between the lever and his hand, and was accompanied by a violent wrench in his arm, wholly unlike what he had ever experienced before. The same effect was repeated when he attempted to touch any part of the boiler, or any iron-work connected with it, provided his other hand was exposed to the jet of steam. He next found that, when he held one hand in the jet of steam, he communicated a shock to every person whom he touched with the other, whether such person was in contact with the boiler, or merely standing on the brick-work which supported it; but that a person touching the boiler received a much stronger shock than one who merely stood on the brick" that supported it.

It need scarcely be remarked, that the scientific world was literally "electrified" by this novelty. Mr. Pattinson, a scientific gentleman at Newcastle, almost immediately afterwards, was enabled, by the electricity thus developed, to produce all the effects usually illustrated by certain class experiments; as, for example, those of attraction, repulsion, &c., &c., to which we need not here refer, for they will come under notice in their proper places. It must not be supposed that the discovery of the electricity excited by evaporation of a liquid was the discovery then made; for this had been well known for a century. The matter of surprise was, that an iron boiler, fixed in the ordinary brick-work, should, under such circumstances, have given any electrical effects whatever. It was seen that the higher the pressure of steam, the greater were the electrical effects evinced; and, perhaps, this led to the discovery of the real cause of the phenomena thus first evidenced.

It was afterwards found, by Mr. Armstrong, that the locomotive boiler afforded the same results. By a series of experiments, he ascertained that it was not the free electricity of the steam *in* the boiler that generated the various phenomena observed. He found the quality of the water in the boiler, together with the pressure of the steam, affected the length and brilliancy of the sparks; and it soon became evident to him and Mr. Pattinson, who also carried on the investigation at another place, that the cause was

external to the boiler, and had direct connection with the passage of steam through the jet into the air.

It was left to Faraday to discover the real cause of this development of electricity. He proved it to be due to the friction of the minute particles of condensed steam against the surface it came in contact with. In other words, the dry steam merely acts as a mechanical force to propel wet steam, or that holds water in suspension, and so causes the friction of the latter —just as the friction of the glass plate of the ordinary machine, by the rubbers, produces free electricity.

Faraday showed, in a lecture at the Royal Institution, that it was neither evaporation nor the pressure of steam that caused the evolution of electricity from a steam-boiler. In illustrating his views before the audience, he employed a boiler insulated by cakes of shell-lac. A pipe, of small bore, and ended with a jet, proceeded horizontally from the side of the boiler; between the jet at its further end and the boiler, a metal globe was inserted, so that any liquid might be placed in the latter whilst the steam was passing from the boiler into the open air. By means of an electrometer (that will afterwards be described), any, even the faintest, indication of free electricity could be detected; whilst, if the latter was abundant, the sparks afforded, of course, equally proved the fact. He showed, by this apparatus, that it was not the issue of steam simply that caused the development of free electricity, for none was evident when *dry* steam was made to issue; but, on putting *pure* water into the globe, intermediate between the jet and the boiler, the electricity was afforded in abundance. He thus proved, what we before remarked, that it is the friction of the particles of water driven by the steam against the sides of the jet, that causes the electric phenomena given by a hydro-electric machine; hence its name, *hydro*, from the Greek word signifying water.

But beyond the sagacious discovery of this fact, Faraday made one equally important. Above we have italicised the word *pure;* and we now draw attention to the ingenious manner in which Faraday proved his position. We cannot do better than quote his own remarks made at the lecture. After having shown the necessity of water in the steam, he proceeded to prove that pure water alone would afford free electricity in the hydro-electric machine.

"I have here some Glauber's salts [sulphate of soda]; I will take a small portion of their crystals, dissolve them in water, and you will find that, if I put the water into the globe [see preceding description of the apparatus he used on the occasion], all these effects will cease. If I establish this point to your satisfaction, you will have no difficulty at once in ascertaining the kind of evaporation; because all ordinary water—at least all the water of the sea—must be more saline than this. I have used the salts that are in the sea, and they have all the same effect—that of entirely destroying the evolution of any electricity from the steam in the boiler. Now, here is a small portion of salts; and if we evaporate as long as we please, it will give us no electricity; but if you use common distilled water, free from impurities, you get the electricity directly; but put a little of this solution with it, and you perceive it stop immediately."

Here we must make a short break, to explain what Faraday did and meant. In the following cut will be noticed a glass jar, within which are

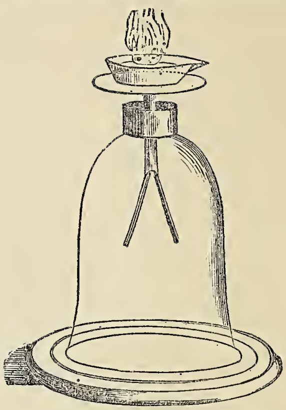


Fig. 98.—The Electroscope.

represented two pieces of gold leaf, that, so long as no free electricity is present on them, will remain suspended parallel to each other; but the instant they are electrified they start apart by electrical repulsion. In the above cut, at the top, is shown a basin, from which steam is issuing; and it is intended to represent the effect—just related by the quotation from Faraday—that the evaporation of *pure* water produces. By this piece of apparatus, which is what is called an *electroscope*, he demonstrated the position he above advances. Continuing his remarks after this explanatory digression—

"I now put in a very small portion into this globe [of the apparatus already described as attached to an insulated boiler], and now I expect to have no electricity. First, the steam mingles the whole together. I have got no electricity in that water: all is perfectly quiet. But if I draw off this water, and substitute distilled water, I shall have electricity produced again. I will try this experiment; for it is a very singular one. I will draw off the impure water, and wash out the residue; and now you will see that the distilled water will bring everything up to its first state again. Now I have got cold distilled water: I will warm it up. I have hardly washed out the passages enough; but still there is the effect—the water comes forward. The water must be quite pure; even the common water that we use, which is nearly pure, will not answer the purpose. I will trespass a little upon your time to show that the water which is supplied by the company at Paddington, and which, for all ordinary purposes, is very good, will not allow the formation of electricity. All I have to do is to draw off this water, and to introduce four ounces of this common water, and you will find it has salts

enough in it to prevent the evolution of electricity as we had before with the pure water. I spent many weary hours in the laboratory in endeavouring to produce this evolution of electricity, and could not succeed. I could not tell why, until, at last, I used a portion of distilled water, and then I succeeded. Over and over again I have had these annoyances occur, until, at last, I arrived at the truth—that a little admixture of saline matter gives a conducting power to the water, so as to prevent the formation of electricity. If I get a boiler that will stand a higher pressure than this, I find that water which is a little impure will give me electricity; proving, that the greater the pressure, the more free the evolution, and that an interfering cause like this can be counteracted. I must not, however, stop longer upon these *minutiæ*, although they are very important, and help to set us clear from the notion that it is evaporation, for how can this electrical phenomenon to which we have alluded be caused by evaporation, when, as we have seen, in order to produce the effect we must have pure water; and when we know that there is no such water on the surface of the earth?" This concluding paragraph refers to the intention of Faraday to refute, by the experiments shown, the theory that the atmosphere is charged with free electricity by the natural evaporation of water from the surface of the earth in forming clouds.

Having thus traced the steps by which the real cause of the action of the hydro-electric machine was discovered, we next proceed to describe that formerly in the London Polytechnic, and to which reference has previously been made.

In the following cut this machine is represented.

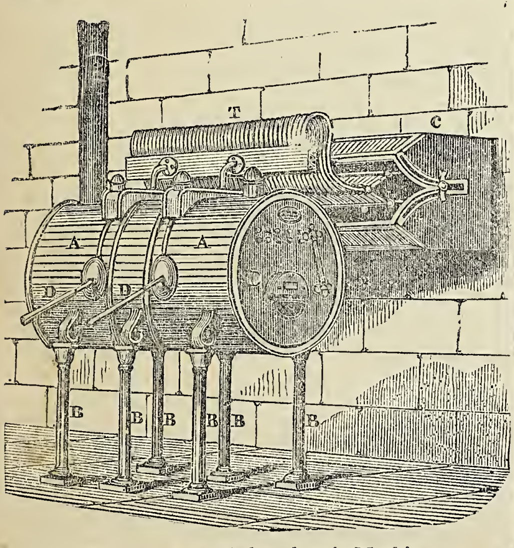


Fig. 99.—The Hydro-electric Machine.

A A is the boiler in which the steam was generated. The boiler had a central tube, containing the furnace and ash-pit. The door of the furnace is seen in front; and over it, on the right, is the water-gauge. No steam-pressure gauge was employed. It was insulated by six dark-green bottle-glass legs, B B. C is a box fitted into an opening of a wall, whence a flue arose to carry off the waste steam from the blowing-tubes. This box was filled with iron spikes; and the whole arrangement could be shifted nearer or further from the ends of the tubes, as required to modify the length of spark. By means of the handle, D D, steam was admitted into a series of tubes bent into the form of the letter S, and represented at T. The ends of these tubes most distant from the boiler, and facing the iron-spiked box, were fitted with jets of partridge wood, through which the steam issued. The steam from the boiler became partially condensed in its passage thence through the tubes, and hence generated pure water. The jets were constructed internally like the bat's-wing gas-jet, so as to afford as much friction as possible. A safety-valve was provided, and the smoke funnel had over it a movable hood, that could be raised during the production of the electricity. Hard spring water was used to fill the boiler—no care even being taken in respect to its purity. Indeed, the water abounded with soluble salts of iron, lime, potass, soda, &c. The amount of pressure we usually employed was ninety pounds on the square inch; but generally, during each fortnight, tested the boiler up to 120 pounds, so that no danger could arise of its bursting in the presence of an audience. In size it was about two-thirds the average length of an ordinary locomotive boiler, and about two feet six inches in diameter. The plate, we believe, was of best Staffordshire boiler-iron, and three-eighths thick; but cannot speak with certainty on these two points. Such, however, would be a safe thickness in constructing a boiler of the size named.

The effects producible by this hydro-electric machine, when in good order, and under favourable circumstances of weather, &c., were of the most magnificent kind. A surface of six square feet in a single Leyden jar was charged in a few seconds; and almost all attempts to fully charge the jar, especially during the prevalence of an east wind, resulted in its fracture. The report produced by its discharge was exceedingly violent. We have charged twenty-four jars, each of six feet internal surface, in less than a minute; and when the electricity thus accumulated was allowed to pass over gold or other leaf enclosed between two pieces of window-glass, each eight inches wide by two broad, the glass was entirely broken into fine fragments, the gold leaf being forced into it in detached pieces.

A chain, consisting of alternate beads of glass and pieces of cork, coated with tin-foil (the whole exceeding 150 feet in length), could be kept illuminated for any length of time. The shock obtained by presenting the knuckle to the side of the boiler, when only a two-inch spark was afforded, was generally sufficient to prostrate the strongest man. A charge of a dozen jars, of the size already named, was fatal to a large

Newfoundland dog, and apparently harmful, if not dangerous, to man ; as an assistant who thus suffered, was rendered, for some time, incapable of following his usual duties—not that he was frightened, for he had been long acquainted with the power of the instrument.

Fine iron wire, of about seven feet in length, was instantly deflagrated by a discharge from twelve jars of the size previously named. The spark, or rather *aura in vacuo*, was of the richest purple, and could be conveyed through a distance of from five to seven feet.

It will be unnecessary further to remark on the power of this instrument. Our experience led us to believe that an average pressure of from 90 to 100 pounds per square inch of steam gave the best results, although we have run the pressure up to nearly 150 pounds per square inch. The latter pressure, however, was not by any means safe to work in public ; and, of course, it could only occasionally happen that private experiments could be carried on with such an apparatus, except with great cost of time and trouble. As a rule, we found that the length of spark was in arithmetical relation to the pressure ; but such a rule can only be taken in connection and on dependence with all circumstances of damp weather, wind, &c., &c., that every practical electrician will well know how to make full allowance for.

Having thus described all the chief kinds of apparatus used for the production of frictional electricity, we next proceed to mention such as are required to show its effects, to measure its quantity, and that are employed for a variety of other purposes.

One of the most important instruments of the electrician is the *electroscope*, most frequently, but very improperly, termed an *electrometer.* The former designation implies an instrument by which the development of frictional electricity is *seen ;* the latter, that by which it is *measured.* The derivation of the two terms, *electro-see* and *electro-measure,* is evident on referring to their Greek bases.

One of the simplest forms of an electroscope, is that in which two pith balls are suspended from a holder, as represented in the annexed cut. There they are shown in an excited state ; that is, we suppose that either a rubbed glass tube, or rod of sealing-wax, has been presented to them. Hence the effect of repulsion, arising from a similar electricalisation (see *ante*, p. 175). The experiment is highly instructive to the young electrician. The foot is formed of dried wood ; and the support, bent at the top, is of brass wire. The threads from which the balls are suspended should be silk. On first presenting an excited glass tube, or rod of sealing-wax similarly excited, both the balls will approach either electrified body ; but, "being fully saturated with electricity" (to use an old current phrase), on the removal of the excited tube or sealing-wax, they will immediately repel each other ; and the extent of deviation between the two balls, from a perpendicular line between them, indicates the amount or tension of electricity present in a free state. The latter term, *tension,* will receive greater notice hereafter.

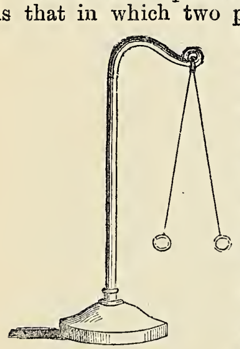


Fig. 100.

The gold-leaf electrometer, or, more properly, *electroscope*—for it measures nothing, but simply indicates—is represented in the following cut. At the top is a brass plate, *a*, from which metallic communication extends to two pieces of gold leaf, *g g*. So long as no electricity in a free state is present, the gold leaves hang parallel to each other, as already explained at p. 11, *ante*, when we were describing the effects of evaporation as productive of electricity. But the moment any electrically-excited body is brought near to, or in contact with, *a*, then the two gold leaves at once separate, and, like the pith-ball electroscope already named, indicate the tension of the electricity present by the amount of the divergence.

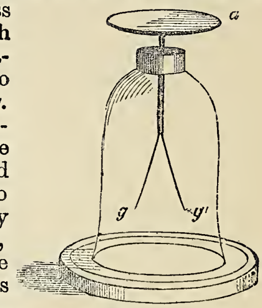


Fig. 101. The Electrometer.

But this electroscope, and all others, have another use, that is highly instructive to the beginner. Supposing, for example, that the pith-ball electroscope (illustrated by Fig. 184), or the gold-leaf electrometer last described, be excited by the approximation of a rubbed glass tube. Whilst either the balls or the gold leaves are so separated, bring near to them an electrically-excited piece of sealing-wax ; then it will be found that, in place of the balls or gold leaves continuing their divergence, they will instantly collapse, and attain a parallel and perfectly perpendicular direction, provided that they were, in the first instanee, properly arranged. Now this proves distinctly (see *ante*, p. 175) that the two different kinds of electricity effectually and perfectly neutralise each other. Neither exceeds nor falls short of the requirements of the other. The positive, or vitreous electricity, equals the negative, or resinous ; and consequently, in the instances to which we refer, the pith balls or gold leaves indicate a restoration of what we technically call the *electric equilibrium.*

The invention of the gold-leaf electrometer last described is ascribed to Mr. Bennett. It is readily made in the following simple manner. *a* should be a small brass polished plate, with all edges carefully rubbed off : from it should extend a piece of flat metal, coated with shell-lac dissolved in spirits of wine, as far as the inside of the neck of the glass jar enclosing the metallic leaves. The latter are attached to the shell-lac solution by its cohesive power; but

each leaf should be made to keep metallic contact with the circular piece of brass, *a*, called the cap. The object is to excite separately, but simultaneously, each and both pieces of gold leaf. In cutting these, all rough edges should be avoided, because, if such be present, the leaves are apt to stick together, through those edges coming in contact. The external glass jar is chiefly employed to keep off currents of air. But if coated internally with a strip of tin-foil on each side, facing the sides of the gold leaves, and continued outside, so that the tin-foil slip may be placed in connection, on either side, with a good conductor, the sensibility of the instrument is greatly increased. It is of the utmost importance that the glass and brass external to this form of electroscope be kept as dry as possible, for otherwise all signs of minute electrical excitement would fail to be discovered.

But the preceding, as already mentioned, while valuable as means of detecting the presence of free electricity, fail to give its measure. Coulomb, adopting the principle of torsion, first enunciated by Michell, was the first to give us an instrument by means of which we could in any way *measure* the amount or tension of the electric force manifested under any particular circumstances. Nothing is easier than to weigh any body, or, in other words, to ascertain the relation of its bulk and mass to the gravitating force of the earth; for that, philosophically speaking, is simply what the ordinary process of weighing effects. But to determine the amount of electrical and magnetical forces is a very different affair. In the former case—that of gravitation—we have a universal force exerted unlimitedly through space, according to the mass of the attracting body. This body is, on the smallest scale that we know, the moon; on the largest scale, the sun. But, so far as practice is concerned, we have, in daily life, only to do with the attractive force of the earth. A pound at the equator weighs less, as judged by the spring-balance, than a pound does at the poles, because the latter, being nearer to the centre of the earth, attracts the pound weight more powerfully. But the absolute difference of distance between the centre of the earth from the equator, and its distance from the poles, is about thirteen miles. The

Equatorial diameter of the earth is			7925·465
Polar	do.	do.	7898·972
Difference in miles	. .	.	26·493

And yet, with this difference, the difference of weight of a pound is but slight. But when we have to estimate the reduction of force, obedient, nevertheless, to the law of the inverse square of distance, in regard to electricity and magnetism, fractions of an inch become of the highest importance. Indeed, we once possessed an electro-horse-shoe magnet, that when well excited by a powerful battery, sustained on its poles a weight of several tons. But at an inch or two from the surface, a common sewing-needle was attracted with so little power, that it could not be suspended in the air if any opponent force prevented its close approximation to the electro-magnet poles.

Hence will appear the value of Coulomb's method, by which the torsion or power to resistance by twisting is made a measure of electricity and magnetism. In the ordinary Bennett's gold-leaf electroscope, the greater the divergence of the gold leaves from the perpendicular, the greater ought to be the evidence of free electricity. But its indications are at once sudden, uncertain, and not to be depended on. In Coulomb's torsion instrument, as illustrated in the annexed cut, *a* represents a horizontal needle of shell-lac, fitted with a ball at each end; *b* is a ball conducting electricity from any excited body. The needle, *a*, is suspended by *c*, internal to a glass tube, *c* being a silk filament; and it is the resistance of this to the act of twisting, by the repelling or repulsive force acting on *a* from *b*, that constitutes the measuring force of the instrument.

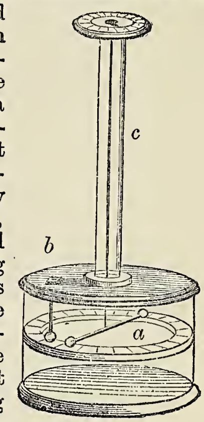


Fig. 102.

Hence the resistance to torsion or twisting by the silk thread to the motion of *a* from *b*, constitutes the value and characteristic quality of the instrument. If the silk thread were so rigid that it could not be moved by the repulsive force of the electricity, of course no admeasurement of the force could be made. It hence follows, that a proper arrangement, in respect to the resistance to torsion, of the filament, affords to the experimenter an admirable and exact instrument. At the same time, it must be admitted, that the results obtained by this, and all other electrometers, are relative or comparative rather than absolute. A modified form, but a most ingeniously-constructed one, was made for Sir W. Thompson, according to his directions, for estimating the force of the electric current transmitted through the cable, in laying down the Atlantic telegraph cable of 1865 and 1866.

In charging a Leyden jar, an instrument, combining the characters of an electroscope and of an electrometer, is frequently used, because, by its indications, the fracture of the jar by an overcharge may be avoided. It is illustrated in the annexed cut: *a* represents an upright stem, on which is fixed a kind of dial, *b*, divided into degrees; *c* is a ball, held by a rod, and the repulsion of this from the stem, *a*, by the charging of a Leyden jar, indicates the progress of the latter; *d* is a conical piece, by which the electrometer is inserted into the

Fig. 103.

knob of the Leyden jar, communicating with the inside of the latter. When we describe the construction and use of the Leyden jar, our readers will more fully understand the use of this arrangement. In practice, however, we have never employed it; for, after some acquaintance with the usual power of any kind of electrical machine, a keen eye and ear are generally quite sufficient to regulate the extent of a charge that a jar can bear without danger of fracture; and in almost every case, unless the same jar has been repeatedly used and proved, in respect to the amount of charge it can bear, this form of electrometer may lead to very deceptive results; for few glass jars are sufficiently homogeneous in their construction by blowing to be trusted, except by the experience of repeated previous trials.

The Leyden jar specially deserves notice. Its early discovery was due to the combined experiments of Muschenbroeck, Allamand, and Cunæus, about the year 1743–'4. The first impression that the discovery of the results of charging such led to, was, that the electrical action was accumulated. We forbear, for the present, to discuss the question, because, in our future pages, we shall have to enter into a dissertation on the entire practice and theory of electric induction (see *ante*, p. 177). The initiative of the modern Leyden jar was a glass vessel containing water, having a nail inserted in contact with the liquid. By pure accident, the operator, holding the external part of the glass vessel by the hand, at a distance sufficient to allow of insulation between the interior and exterior of the glass, kept the arrangement in such a manner to the prime conductor of an electrical machine, that a high state of induction was produced. Muschenbroeck then presented his knuckle to the nail, when he imagined that the jar "was full of electricity;" and received a shock that made him express the opinion, that the reward of all the kingdoms of Europe would not induce him to receive a second. Had he lived in our days, he would have laughed at his own fears. But, as already remarked, the novelty of the affair lent an aid to his imagination.

A Leyden jar essentially consists of a glass jar coated internally and externally with tin-foil, an interval of at least five inches being left between each coated surface. For example, an ordinary confectioner's show-glass may be coated to within about two inches of its internal and external height with tin-foil, easily purchased at any chemist's. The glass should be chosen as thin as possible, and quite free from flaws of any kind. Of course, the ratio of the diameter to the circular surface is as 1 to $3\frac{1}{7}$; or, in other words, supposing that the jar proposed to be covered has a diameter of three inches, a piece of tin-foil equal to not less, practically, than ten inches, should be cut; with a depth corresponding to that of the jar—less about two inches on each upper side between the inner and outer coatings. If the two coatings of tin-foil be covered on one of the sides by common paste, they will adhere to the glass vessel. A Leyden jar, of ordinary form, is represented in the annexed cut. *b* shows an external surface of tin-foil, corresponding, in all respects, to the internal one; but both the inside and outside bottom of the jar should also be coated with tin-foil, this covering being also made to communicate with the side coatings of the jar. In the annexed cut, the unshaded part shows the intervals between the inside and outside coatings of the jar.

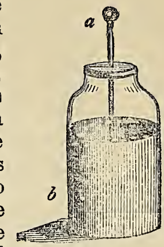


Fig. 104.

a is a brass knob fitted to a brass wire, which should, inside the jar, be attached to a chain, that rests on the lower coating of the jar inside; the object being to keep up a continuous electrical conduction between the knob, *a*, and the internal tin-foil coating when presented to the prime conductor of an electrical machine. It is equally necessary that the external coating should be in contact with a good conducting object; and hence, if a number of such jars are to be charged in the manner to be presently described, a connection, by means of a good copper wire (not a brass chain), should be made with a gas or water-pipe.

The method of charging a Leyden jar is as follows:—In Fig. 105, *a* represents the prime

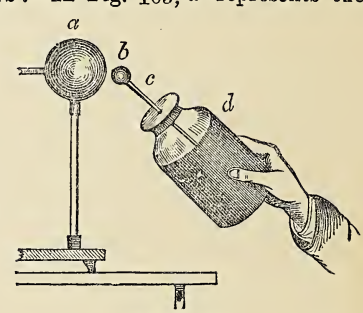


Fig. 105.

conductor of any form of electrical machine; *b* is the knob of the Leyden jar, whose conducting rod to the interior is indicated by *c*, while the external coating is shown by *d*. In this illustration the hand of the experimenter is supposed to afford a means of communication with the earth, so as to maintain the necessary continuity for electric induction; but, except for small jars, the method is generally ineffective: it is always desirable to connect the exterior of the jar with an excellent and well-diffused conductor.

On first presenting the knob of the Leyden jar to the prime conductor, the sparks from the latter seem to proceed with great rapidity. But gradually they diminish in number, so far as sound and sight afford any indication. This is a sign that the jar is becoming rapidly charged—the time required for which will greatly vary, according to the dampness of the weather, and a variety of other circumstances, to which we shall have subsequently to refer. If the charging be

carried too far, two results may take place. A spontaneous discharge may occur between the inner and outside coatings, which, if the jar be held by the hand, will be perceived by a shock given to the experimenter, accompanied by a spark and a loud report: or, if the jar be of bad glass, it will be fractured—a matter of common occurrence when a high charge is given to a jar, especially when the air is very dry.

If any of our readers desire to choose an efficient Leyden jar—that is, the glass jar antecedent to coating—we advise them as follows:—First, to choose the glass as free as possible from every flaw in respect to wrinkles, observed by looking through the jar; next, to have the glass as thin as possible; and, lastly, to take great care that no spots or specks occur in it. We have made and purchased jars of almost every kind, from a half-pint's capacity to that of eight or ten gallons, and yet could scarcely pick out of some scores, perhaps hundreds, a dozen that could be depended on for receiving individually a charge that could be reckoned as an average in the whole of what the multiple should have afforded. One by itself would do admirably well; but placed, as we shall presently explain, in contact with another, disappointment alone was the result. But this will be more particularly explained as we describe the—

Leyden or Electric Battery.—This consists of a number of Leyden jars, so arranged that all their outsides are connected by means of a wire, and their insides by similar means. The following cut illustrates such an arrangement. *a a* re-

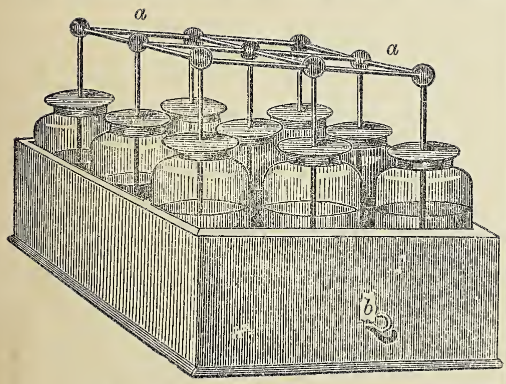


Fig. 106.—The Leyden Battery.

present the connection of the insides of the jars by means of brass rods. All the outsides of the jars are connected by a wire twisted round each, and a terminal being brought into contact with a hook, *b*, which is to be attached, by means of a wire, to a gas or water-pipe, to ensure full efficiency of the whole arrangement. Many persons consider that simply resting the wire from the external part of the Leyden battery on the floor of a room is sufficient. They are utterly in error. For example, we have charged twenty jars, each having a surface of ten square feet, by the hydro-electric, described at p. 185, *ante*. The exterior of the battery was connected, by means of a copper wire, with the iron pipes of the gas arrangements of the Polytechnic Institution, Regent Street; and although the whole institution was replete with such pipes, sparks not only could be received from them, but, *in exceedingly dry* weather, the passers-by in Regent Street, within two hundred feet of the institution, could get sparks from the lamp-posts. We admit that this is an extreme case; but such simply illustrates the necessity of affording every possible means for permitting full and complete electric induction in charging a Leyden battery.

Another method of arranging the Leyden battery is illustrated in the following cut; but we do not recommend it. The jars are repre-

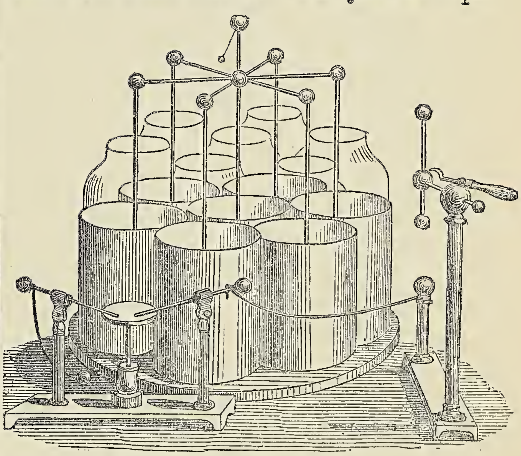


Fig. 107.—The Leyden Battery.

sented as open at the top. Now, whenever a jar is charged by electricity, there is, to a large extent, a kind of *convection* going on. By the term *convection*, we mean a *carrying upwards*, that may be illustrated as follows:—If a glass vessel be filled with common water, and a funnel with a long tube be inserted in such a manner that its lower end shall rest at the bottom of the vessel, a solution of sulphate of copper may be so poured in, that it shall, by its superior specific gravity, displace the lighter water, and occupy the lower part of the vessel. So long as the temperature of the two liquids is the same, the solution of the sulphate of copper will remain at the lower part of the glass, and the water above it. But if the lower part of the vessel be heated, then the sulphate of copper solution, although of so much higher specific gravity, will rise through the lighter water, and form a series of currents upwards.

Similarly, when Leyden jars, such as are represented in the preceding cut, are charged, a *convectional* effect is observed. In other words, just as, in the experiment last suggested as illustrative of our subject, a current of air, caused by *convection*, or *upward carrying*, is produced, and much of the charge is dispersed in the atmosphere; the more so in proportion as the latter is charged with moisture. The apparatus connected with the Leyden battery, represented

in the last cut, will be more fully explained presently.

The management of a Leyden battery, so as to afford its maximum effects, is a matter as difficult as any in the range of experimental science. We can, without hesitation, state that we have had at our disposal, at various periods, the most powerful electrical arrangements, frictional, voltaic, and electro-magnetic, that have ever been constructed, whether for private or public use; but must give the palm for uncertainty of results to the Leyden battery. For example, on consecutive nights, with a dry east wind, and severe frost, we have tried Leyden jars separately to test their value, the test being breakage under spontaneous discharge, and the length of time that the spontaneous discharge required to be effected. Selecting such test-jars, we have found that for a time they would give admirable results. In fact, a few would give a shock after being laid aside for a day or two, on presenting the knuckle to the knob communicating with the interior, holding the exterior by the hand; that is, not by re-charging, but simply by the residual discharge, showing certainly a surprising amount of insulation. But in damp weather, despite the hot air of charcoal fires being passed over them, these jars, apparently similar in power under the previous conditions, would vary greatly. Doubtless, this was owing to the chemical constitution of the glass of which the jars were made. Some kinds, containing much soda instead of potash as the glass-producing alkali, would attract moisture from the atmosphere, and retain it on the surface, of course destroying their insulation (see *ante*, p. 176). To remedy this, we put on our glass jars three feet high, and eighteen inches in diameter, an external coating of shell-lac beyond and above the internal and external surfaces of the tin-foil coating. Out of seventy-two jars, with every possible precaution, and literally regardless of expense, we never found twelve that would work harmoniously together; by which we mean, that supposing a certain amount of electrical excitation was afforded by the hydro-electric or plate machine, a regular and definite result could only be depended on by the use of such picked jars.

These failures and facts will impress on the minds of our practical readers the necessity of care in the choice of the glass, in every respect, that they propose to select as a material for making an electric or Leyden battery.—We next pass on to consider some points of apparently minor importance, but that are really little inferior, in that respect, to certain already mentioned.

If the cleaning of the exterior of a jar be left to an assistant, the probability is that he will leave the jar covered with fibres from the cloth or silk that has been used; or, more possibly, a damp hand will have communicated a considerable amount of moisture. The upper edges of the tin-foil coat, both internal and external of the jar, will be, in an average of cases, rough; and, from the influence of points that we shall subsequently have to notice, a large amount of the "accumulated electricity" will be lost. Again, a chain, suspended from the wire extending into the jar, and from the external brass knob, becomes liable to oxidation, and therefore impedes the ready charging of the jar. The latter evil is avoided by communicating the interior of the jar with the charging knob by means of a bunch of radiating wires, so that the latter may touch the interior coating of the jar in many points. The great cause of failure in all frictional-electrical experiments may be traced to careless or imperfect connections; to dirt, dust, and moisture; and, lastly, to oxidation of surfaces. But we know not where to end instructions on these points; and, perhaps, if we pursue the subject further, it may be done so to wearying even of our practical readers.

Having described the methods of accumulating electricity after its primary production by friction, the next practical question is its distribution for experimental purposes; but, before entering into this, we must make a few remarks on the effects of *surface*, but especially *pointed* surfaces in that respect.

The definition of the term *point* is, like many others in frictional electricity, more comparative than real. For example, with a small electrical machine it would require a point as fine as that of a pin's head to produce effects presently to be described. But with the electrical development of one of the largest of electrical arrangements, frictional or hydro-electric, a *point* may be simply a small knob. We have pleasure in here quoting the opinions of a very careful observer of science, whose discoveries have been much neglected—we refer to Dr. Scoffern. He remarks on this point, and in reference to lightning conductors (which we shall have to discuss hereafter)—

"Great discussion originally took place amongst electricians as to the proper shape to be given to the extremity of these lightning conductors. One party advocated spherical terminations—that is, knobs or balls; another, pointed extremities. There remains no doubt on this matter now. Points are universally accepted as being the preferable form; and the reason that they are preferable will readily appear. * * * * An observance of the relative effect of points and knobs, applied near to the charged primed conductor of the electrical machine, at once settles the controversy. A more satisfactory way of demonstrating the relative influence of points and knobs (or balls), however, is supplied by the following experiment:—To the prime conductor [see *ante*, Fig. 94] of an electrical machine attach the instrument illustrated in the following cut, representing a forked conductor, each prong of which ends in a ball; but the balls are of different dimensions. Now it is evident that in proportion as a ball is diminished in size, so does it approach to the nature of a point; founded on an appreciation of which condition is the experiment about to be described. If the operator charge the prime conductor of an electrical machine—of which the forked appa-

ratus is assumed to be, for the time, a part—and if he cause a knobbed conductor to approach

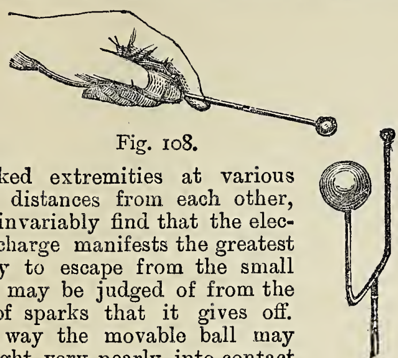


Fig. 108.

the forked extremities at various relative distances from each other, he will invariably find that the electric discharge manifests the greatest tendency to escape from the small ball, as may be judged of from the length of sparks that it gives off. In this way the movable ball may be brought very nearly into contact with the large ball; still the electric discharge will take place from the small one. If desired, the mechanical conditions of the arrangement may be reversed; the forked conductor being held in the hand, and the single conductor fixed: still the result will always agree in this—the electric discharge invariably manifests preference for the small ball."

Incidentally we have already noticed the influence of points in dispersing electricity; and have recommended that all metallic surfaces be kept in a perfectly clean and polished condition. If a pointed wire be fixed on the prime conductor of an electrical machine of any kind, the dispersion of the force takes place to an extent that will render it impossible to charge a jar or battery to anything like an available extent. In working a machine in the dark, with a pointed wire fixed to the prime conductor, the phenomena called the "brush" will be apparent. Or if a pointed wire be presented to the conductor in the manner represented in the following cut,

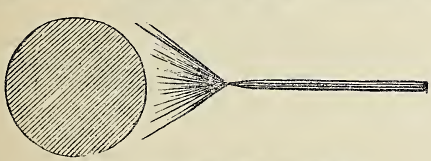


Fig. 109.—The Electric Brush.

precisely the same effect takes place—a hair-like radiation of a purple colour is afforded; and it will be impossible to produce the spark that ordinarily proceeds when a knob of brass is presented to, at a short distance from, the conductor. Hence the reason of the employment, in lightning conductors, of a pointed end. It has, therefore, been found that the radiative or diffusive power of grass and straw is so great, that a few wisps of the latter placed at the top of a hay-stack, will protect it, in the majority of cases, from danger of destruction by lightning. Indeed, it will be within the experience of all our readers, that for a hay-stack or corn-stack to be struck is a matter of rare occurrence, considering their number and extremely exposed position throughout the country.

In using a Leyden jar or battery, a *discharger* is requisite, either for the safety or comfort of the experimenter; for if a large electrical machine and Leyden battery be used in experiments, the result might be serious, and even fatal, were the shock to pass through his system; and even a half-pint jar gives a shock, when fully charged, that is far from pleasant. A great variety of dischargers have been suggested; amongst which the following are of most constant use.

The simplest form is that represented in the following cut. On the right hand is a Leyden

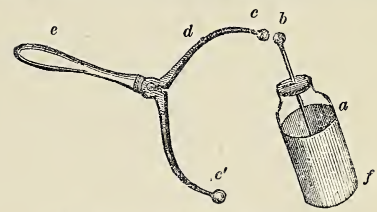


Fig. 110.—The Discharger.

jar, *a*, supposed to be charged. The discharger consists of a thick brass wire, *d*, at each extremity of which is a brass knob. The handle, *e*, is made of glass, or some other non-conductor. Supposing the jar is to be discharged, the knob, *c'*, is brought into contact with the external coating, *f*, of the jar; whilst *c* is brought nearly into contact with *b*. A bright spark, accompanied with an explosive sound, occur simultaneously.

Henley's universal discharger is of much value in electrical experiments; and is represented by the following cut. *a a* are two glass pillars

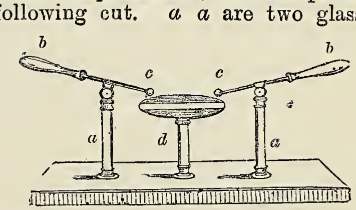


Fig. 111.—Henley's Discharger.

supporting rods of brass, ending in glass handles, *b b*. At *c c* are two brass knobs, that, on being taken off, leave the pointed ends of the rods, useful for certain experiments; *d* is a table, on which the object to be operated on is placed. This is one of the most convenient forms of apparatus for a great variety of electrical experiments. If used in conjunction with a Leyden jar or battery, one of the insulated rods is connected with the outside of the jars, and the other with the inside, by means of a wire: but the latter is kept from the object to be acted on until the battery is fully charged. On such being effected, the glass handle is raised by the hand so as to depress the brass knob on to the object, when a discharge will at once take place.

With powerful batteries, &c., it is always best, however, to use another form of discharger, which, whilst self-acting, can, at the same time, be so regulated as to give any amount of dis-

charge from the battery. In other words, the battery can be discharged at any point of its capacity for electrical accumulation. In all kinds of dischargers, the object is not only to direct the charge, but also to prevent the operator from receiving any of it in his body. Now, with large batteries, even a three-feet glass rod by no means insulates the charge so as to render it safe to discharge the battery by such an instrument. But that which we are about to describe is perfectly safe, and, as already stated, spontaneous in its action. It is represented in the following cut.

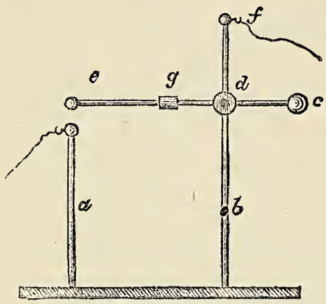


Fig. 112.—Battery Discharger.

a is a glass rod, terminating at the top by a brass knob; and this latter is placed in communication with the object intended to receive the charge, by means of a copper wire: *b* is also an upright glass rod, supporting a lever of brass, *e c*, moving on a pivot as a fulcrum at *d*. This portion of the apparatus is connected with the inside of the battery jars by a wire proceeding from the knob, *f;* whilst the outside of the battery is connected with one part of the object intended to receive the shock or discharge; *g* is a brass slide, which, by being approached to *e*, increases the tendency of the latter to approach the knob above *a;* or, being shifted towards *d*, diminishes that tendency. It is evident, therefore, that by shifting *g* nearer to, or farther from, *d*, a high or low degree of charge can be given to the battery. The effect of the charge is to induce an attraction between the knob, *e*, and that which caps the glass rod, *a*. Supposing, for example, that, at the commencement of charging a battery in the usual manner, the arm, *e g d c*, is horizontal. As the battery becomes charged, the attractive force of electricity tends to cause the knob, *e*, to bend down the rod to the knob at the top of *a;* and, shortly before they come into contact, a bright spark passes, attended with a loud noise, and the battery becomes discharged through the object under experiment; the amount of the charge capable of producing the depression of the lever depending on the position at which *g* is placed. The action of this discharger leaves nothing to be desired in respect to safety, certainty, and precision of action.

In Fig. 18, *ante*, representing a form of Leyden battery, two dischargers will be noticed. The one is Henley's, already described; and the other, on the right, is intended to effect the same results as we have just described in connection with the balanced discharger. But the one to which we now refer, as illustrated at p. 16 (Fig. 18), is regulated by the hand before the charge is communicated to the jars; that is, the vertical brass rod, ended by two brass knobs, is adjusted at any desired distance from the knob beneath it; and this distance, greater or less, determines the quantity of charge that will accumulate before the discharge of the battery takes place.

For a description of other numerous forms of electric dischargers, we must refer our readers to the illustrated catalogues of the instrument-makers; for their description would require too much space at our hands. We may remark that almost every maker of such instruments has brought out "improved forms."

A curious form of gutta-percha machine was invented many years ago, and was, we believe, exhibited at the Exhibition in Hyde-park, in 1851. It consists of an endless band of gutta-percha, running over two rollers. The rubbers are formed of hard hair-brushes; and its general construction is illustrated in the following figure.

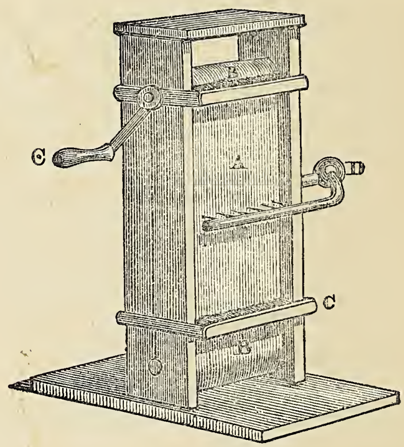


Fig. 113.

A represents the band of gutta-percha; B B are the two rubbers; C is the handle which turns the upper roller; the under one moving by the friction of the gutta-percha against its surface; D is the conductor, which extends in two arms, ended with points facing the gutta-percha band.

We have thus described some of the most important general apparatus required for the practical study of the phenomena of frictional electricity. As we proceed we shall have to describe many others that have special rather than general uses. But the preceding—a stock of copper wire, tin-foil, brass chain, and a few other sundries—will be sufficient for the beginner; and the general use of all will become apparent as we investigate the effects of electricity, especially as, while doing so, we shall suggest means as simple as possible that may be adopted to try the experiments.

CHAPTER IV.

THE GENERAL EFFECTS OF ELECTRICITY PRODUCED BY FRICTION.

AS all forces are simply evidenced by their action on matter, their manifestation is readily effected. We drop a stone from the hand, and, as it reaches the ground, we feel conscious that something of an attractive nature must exist, by virtue of which the stone falls, instead of rising in the air. And so in every instance in which we observe the action of force on matter—the external effect is made a measure of the force.

In respect to the action of heat, light, electricity, and magnetism, however, we have very especial effects; and these lead us to divide such results under the different divisions of calorific, optical, electrical, and magnetical branches of science. Not that such distinctions have, in regard to the laws of nature, any reality; on the contrary, we must simply regard them as an accommodation, for the present, of the want of man's knowledge to the absolute laws of nature. When we say that a body is attracted towards the centre of the earth, we merely state a fact; but if we attempt to measure the amount of that attractive force, we indicate that the force is, to a certain extent, under our control. We may be ignorant of many of the facts of the case; because in the discovery of these lie the essential points of scientific investigation.

In regard to electricity, it will have become apparent to most unscientific readers, that many precautions are necessary to procure accurate results; but, for the present, we shall be content to bring before them simple, but effective, illustrations of what the electric force is capable of. It may certainly be termed a great mystery: scarcely a month elapses but some new discovery is made in regard either to its power or extended influence. We have experimented on it for about forty years; and the longer we devote attention to the subject, the more fully do we become convinced of our ignorance of its nature, laws, and powers.

But this should not discourage any who would venture on the study of the science. What is *not* known is the field of inquiry; and the extent of that field is only to be measured by the infinity of the Creator of all the forces of nature. Little by little we acquire additional knowledge; and thus, step by step, we arrive at some result that affords a stand-point whence we can view a special division of nature's phenomena. Thus we gradually free ourselves from previous errors; and, by experience, attain that highest characteristic of the philosopher—moderation in respect to philosophic speculation. Alas! that modern experimental philosophy so much lacks Bacons and Faradays among its ranks.

But to turn to the practical part of our subject. The general effects of frictional electricity—and we are still continuing an elementary introduction to them—may be properly divided into those of a *luminous*, or light-producing character; the *calorific*, or heat-producing; the *mechanical*, or those effects that result in the breaking-up of a body by violent disruptive force; the *chemical*, in which the composition of a compound is disturbed or destroyed, as in the decomposition of water, &c.; and, lastly, the *physiological* effects, that are manifested by violent action on the nervous and muscular systems of animals. We commence with the—

Luminous Effects of Free Electricity.—These are readily evidenced in the most elementary experiments in electrical science. For example, if a glass tube, a piece of sealing-wax, a sheet of paper, the back of a cat, be rubbed, by means of dry silk, and the knuckle of a finger, or a brass knob, held in the hand, be presented near the excited surface, a spark of light will be seen to pass. The reason of this is by no means evident. It was, at first, supposed to be due to a compression of the atmosphere, by which its latent heat and light become simultaneously manifested. But, unfortunately for this theory, it happens that brilliant sparks may be obtained in an atmosphere approaching nearly to a vacuum in its tenuity. It is true, that, in the most complete vacuum that we can attain by means of our air-pumps, the brilliancy of the spark becomes greatly diminished; whilst its colour is simultaneously changed from a blue or yellowish-white, in the open air, to a beautiful purple. Similarly, by sending the spark through different gases, its colour is altered. The experiment of passing the spark through the vacuum of an air-pump is extremely beautiful; and the mode of doing this is represented in the above cut. *a* is the prime conductor of an electrical machine in

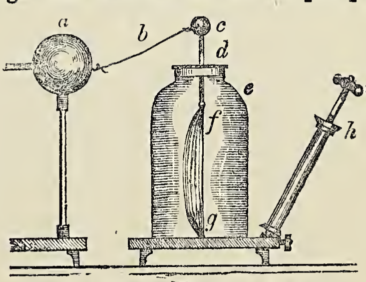


Fig. 114.—Discharge in a Vacuum.

good order, connected by a wire, *b*, to a knob, *c*, of a rod, that fits air-tight by a brass collar, *d*, in a receiver, *e*. The piston-rod, *i*, and the cylinder, *h*, of the air-pump are at once recognisable as of the ordinary form of a single-barrelled machine. Now, if the air be extracted, by means of the pump, from the receiver, *e*, a long spark will pass between *f* and *g*. The length and colour of the spark depend entirely on the amount of exhaustion effected in regard to the receiver. Whilst the length increases, the brilliancy of the spark decreases, just as the process of exhaustion is carried on. For example, supposing a machine, in good working order, and in favourable conditions of the atmosphere, gave a spark of a foot in length; in a vacuum of the best possible description, effected by the air-pump, the length of the spark would be increased to about five feet. Indeed, we have seen, on rare occasions, one of ten feet long, whilst the ten-feet plate machine, mentioned at p. 180, was in good condition, electrically speaking.

We have noticed that the colour of the flame, or spark, varies according to the amount of exhaustion of the receiver of the air-pump. But it also varies in the atmosphere. In a dark room, when a dry east or north-east wind prevails, the spark from an ordinary machine, as taken from the prime conductor, will be of a rich blue, with accurately-defined edges, of a zigzag shape; in fact, precisely resembling an ordinary flash of what is familiarly known as "forked lightning." But if the weather be dull, moist, or, still more popularly, "muggy," the spark has a yellowish, or even reddish appearance, due, most probably, to the effects of the water suspended in the atmosphere. A similar series of effects may be at all times produced in the receiver of the air-pump, illustrated by the preceding cut. It is evident, at first, that if the receiver, *e*, be only placed on the lower brass plate, or stand, just below *g*, that the air it contains must be as much charged with aqueous vapour as the external atmosphere from which it was derived. On working the pump, *i h*, for a few seconds, it will be noticed that a kind of cloud forms, which is due to the separation of the aqueous vapour, that the air contained, from the enclosed air, which, owing to this partial exhaustion, ceases to have the capacity to hold the water in solution. Of course, each stroke of the pump diminishes the amount of aqueous vapour present. But a more ready means of getting dry air inside the receiver, is that of placing a small dish, containing the strongest sulphuric acid, on the brass stand within the receiver. The acid has a very great attraction for moisture, and hence immediately abstracts the aqueous vapour from the air. By thus accommodating these methods to all the circumstances of moisture and dryness of the air, at any period, the influential effects of either, in altering the length and colour of the spark, may be readily studied.

About twenty years ago, when commencing a series of experiments on the discharge in respect to Rhumkorf's induction coil, although well supplied with a variety of the best air pumps, we found great difficulty in maintaining a vacuum. In the ordinary air-pump it is all but impossible to keep the connections air-tight, despite every precaution that can be adopted. Some tap or other opening is sure to leak, and, consequently, to impair the vacuum. We accordingly fitted up an apparatus, illustrated in the annexed cut. *a* represents an ordinary barometrical tube—say, forty inches high—in the top of which is soldered a platinum wire, *d*. The tube being first completely filled with mercury, is to be then closed by the finger at its open or lower end, and the latter is dipped below the surface of some mercury contained in a vessel, *b*. Consequently the mercury in *a* will attain a height, depending on the altitude of the barometer, perhaps, of an average of thirty inches above the surface of the mercury in *b*, and leaving above, a vacuum represented by *c* in the engraving; *e e* are supports to maintain the tube, *a*, in a vertical position. If the platinum wire, *d*, be connected with the prime conductor of an electrical machine, and *b* be connected by means of a wire with the earth, or a gas or water-pipe, so soon as the machine is set to work, a beautiful coloured flame will pass through the vacuum, which is the most perfect that can be attained. By this apparatus, various gases, liquids, and vapours may be easily experimented on, by simply passing them in minute quantities up the tube. A most beautiful series of results may be thus obtained, in respect to colour, and a variety of other effects, with absolute certainty and constancy. It is necessary that the exterior of the tube, *a*, be kept quite dry, for reasons already repeatedly given.

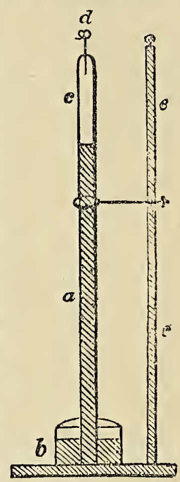


Fig. 115.

We have already suggested a very pretty experiment, by which the effect of the electric spark may be noticed, as resulting from the use of alternate glass beads and pieces of cork covered with tin-foil (see *ante* p. 185). Another beautiful effect results from passing the spark through empty egg-shells, in a manner represented in the following engraving. *a* is the prime conductor of an electrical machine; *b* is a discharger, the use of which has been already described at p. 191, *ante*; *c* is a brass knob suspended from an insulating glass rod, *b*, and connected with copper wire passing through any number of empty egg-shells, *d d d d*. The wires are divided, within the shells, by an interval of half an inch; and the bottom wire, *e*, is connected with the earth or a gas-pipe. So soon as the electricity of the machine passes from the conductor through the eggs, each of the latter will appear illuminated by the spark passing between the intervals, and one of the pret-

tiest illustrations of the electric spark is thus afforded.

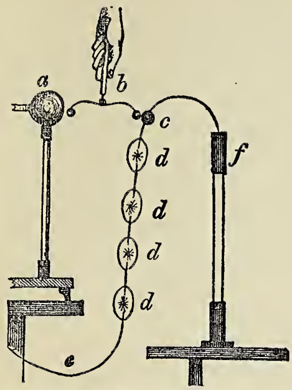


Fig. 116.—The Luminous Discharge

A careful observer, constantly watching the spark produced by a large electrical machine, will notice great differences to exist in respect to its shape. Much of this variety of form doubtless depends on the conducting matter, such as dust, &c., floating in the atmosphere. In electrical, as in chemical experiments, even the most common cannot be repeated without perceiving great variations; that is, if a sharp and educated eye is employed.

We have already noticed that a pointed conductor produces a brush instead of a spark (see *ante*, p. 191). But from a pointed or radiating edge another effect may be observed. For example, in the following cut a piece of apparatus is represented that shows a current of air to be driven from pointed electrified conductors. *a a a a* are pointed wires fixed on a stem, that can rotate on a pivot, *b*. This is supported on a brass wire, *d*, which rests on the prime conductor of an electrical machine, *c*. When the machine is put into action the wheel will commence to rotate; and if the experiment be conducted in the dark, the phenomena of the electric brush will be seen at the points of the wires, *a a a a*.

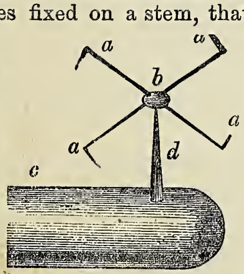


Fig. 117.

The repulsive action of a pointed conductor is still further illustrated by fixing horizontally, on the prime conductor, a wire with a pointed extremity. On presenting the flame of a candle to the pointed end of the wire, the flame will be quickly deflected, showing a mechanical action on the surrounding atmosphere.

Heated air seems to present less resistance to the passage of an electric discharge than cold air. For example, the discharge between two points an inch apart, if effected by the inductive electricity of a Rhumkorf's coil, may be extended to a distance of two or more inches by intervening the flame of a spirit-lamp; and precisely the same result occurs when the electric discharge produced by friction is attempted. Hence, to a certain extent, the increased effect of electrical discharge in hot weather, as in the summer thunder-storm; and, similarly, the column of hot air in a chimney under all circumstances; although, in both cases, we notice a kind of opposition to the law of convection of heat; that is, its carrying or conduction upwards by fluids heated at their lower part.

The luminous effects of frictional electricity are, so far as our artificial means are concerned, most powerfully manifested by the discharge of the Leyden jar or battery. The light produced by such arrangement is of the most intense description; and although, comparatively speaking, the size of the spark is extremely small, and its duration infinitesimal in respect to time, its effect is highly impressive. So instantaneous, but yet powerful, is the luminous effect of a highly-charged jar, exposing, on either side, six square feet of surface, that, in repeating the experiment constantly before an audience of from 1,000 to 2,000 persons, we have been unable to exercise the mental faculty of observation before that of the eye had vanished. It must be remembered that the latter organ cannot appreciate a motion of any object, say in rotation, when the speed is such that any part of the object passes the eye at a rate greater in any space than the eighth of a second of time. For example, suppose a wheel was to be made to rotate so rapidly that each spoke should pass the eye in a period less than the eighth part of a second, or the $\frac{1}{480}$th part of a minute. The result would be, that the motion of the spokes would be utterly indistinguishable by the human eye in ordinary daylight, or by artificial light. But suppose that, in the latter case, a spark from a discharged Leyden jar, or battery, illuminated such a rapidly-rotating wheel, it would appear, for the instant, to be perfectly stationary. Hence the ludicrous accounts (at least to scientific ears) of the duration of a flash of lightning. The following experiment, that we tried on a sharp-sighted, but unscientific friend, who was incredulous as to the fractional, instantaneous duration of a flash of lightning, may be both interesting and instructive to others like himself. A few months ago a distant storm of lightning occurred, so far distant, in fact, that the thunder following each flash could not be heard. The circumstance was chosen to illustrate the truth of what we have stated, because the absence of any sound following the flash eliminated a great error, to which unscientific observers are subject. They imagine a definite relation to exist between the action of the optic and aural nerves; whilst, practically, the latter are deafness and stupidity in result, compared with the lively action of the former. It was agreed that we should force a needle's point into the hand of our friend at the instant that we perceived the flash; but so far behind were we, that our friend imagined some seconds to elapse between the appearance of the flash and the prick of the

needle. Simple as this experiment is, we can confidently recommend it as an excellent method of correcting a very popular error. Hence, as was before mentioned, when an electric discharge from a Leyden jar takes place, the rapidity of the discharge, and of the passage of the light, is so great, that what was really believed to be the present is, mentally and physically, the past, in regard to the powers of man.

The luminous effects of voltaic electricity, and of the induction coil, on the contrary, are continuous. Hence the value of either in affording permanent luminous results, especially in the form of the electric light, as produced between two charcoal points. But even this splendid exhibition of electric force is the result of successive, or repeated, rather than of continuous action; but this is a matter that, for the present, is foreign to our subject.

Some highly interesting experiments may be made by availing ourselves of the laws that regulate the production of the electric brush, already described at p.191, *ante*. For example, if a piece of cotton wool, not absolutely dry, be presented to the prime conductor of an electrical machine in good working order, and in a darkened room, a beautiful series of streams of coloured light will be perceived. One of the most effective results of the kind that we have noticed, was that produced by presenting the edge of a broken finger-nail to any part of the hydro-electric machine (described at p.185, *ante*), when the pressure of steam did not exceed forty or fifty pounds on the square inch. Of course, such an experiment required precaution; and we never attempted it unless the whole skin of the body, from head to foot, was externally moist with perspiration. To give an account of the beauty of the brush thus produced would be impossible. A rich purple flame played between the edge of the finger-nail and that of the iron of the steam boiler, accompanied with a sharp hissing sound; and in proportion as the conducting power of the skin was increased by excessive perspiration, so was the beauty of the experiment. It was impossible to attempt to repeat this, in its full effects, by means of pointed metallic conductors; and, as already stated, a person with a dry skin would have been at once thrown down by the violence of the shock that the apparatus generated at even the low pressure named. As a hydro-electric machine, of a size equal to that which has been described at p. 185, *ante*, is not likely to be again constructed, it may prove interesting to many of our readers pursuing electrical science, to relate the following incident, as illustrative of the conducting power of moisture, and the production of the electric glow on a partially conducting surface:—After lecturing, for above an hour, in the large theatre of the Polytechnic Institution—on that occasion crowded, and exceedingly hot—sufficient perspiration had passed to the outside of our dress to render it slightly moist. The audience being dismissed, we had occasion to pass near the hydro-electric whilst the steam was being blown off through the jets, and, of course, when a considerable amount of free electricity was generated. The lecture-room being darkened, the whole of our dress close to the boiler was illuminated by a beautiful purple light, much resembling that of the electrical discharge *in vacuo*, the intensity of the light depending on proximity to the boiler.

The brilliancy of the flash of lightning, of course, exceeds, in that respect, any other form of electric spark, which it really is, only on an enormous scale. But the estimate of that brilliancy or luminosity is, generally speaking, exceedingly erroneous. We must confess to having never seen a thunder-storm in the tropics; but, in our islands, such storms are sufficiently severe to produce results equally fatal with those experienced in warm countries. The result of our observations for at least thirty-five years, leads to the belief that, when a flash of lightning is viewed *directly* by the eye, its effects on the optic nerve of that organ are greatly less than when viewed by reflection.

Two instances, out of many, may be here related as having been personally experienced. In 1863, whilst watching a violent thunder-storm, a vivid flash occurred; and, within 600 feet of the place of observation, a building was completely destroyed. Yet the flash, whilst extremely vivid, and, apparently, of enormous length, had comparatively little effect on our sight. On the other hand, in 1867, when a fearful storm burst over every part of our islands—although, at least according to the law of acoustics, we were distant five miles from the scene of the nearest storm—the *reflection* of the flashes, from a *wet* pavement, was so vivid as to be intolerable to the eye; whilst the *direct* flash—that is, the latter viewed at once by the eye—seemed faint. It must not be supposed that we draw conclusions simply from these two instances; but they are merely adduced as illustrations of what we mean.

It may interest many of our unscientific readers if we here make a few remarks on the psychological and physiological effects that a thunder-storm exercises on various individuals, as an effect of what may be called the electric spark of nature. There is no doubt that every person who, to popularly speak of, "is afraid of a thunder-storm," places him or herself in exactly that position in which terror, apart from electricity, has its utmost effects. In the summer of 1867, more than ten persons died from the effects of some heavy storms on the nervous system, and, in fact, simply through fright. But there is another class, quite free from the latter feeling, who constantly become subject to the antecedent effects of a storm, and are instantly relieved by its occurrence; and in this latter class we are compelled to rank. Scientifically, we have felt, from early days, a deep interest in a thunder-storm; and are not only devoid of fear, but enjoy the spectacle. Yet, immediately preceding it, and during the accumulation of cloud that forebodes the storm, we are by no means behind those who suffer from its actual presence. Appealing to the experience of many of our readers, we shall find a full sympathy for that feeling. It does not.

so far as we have observed, seem traceable to any particular temperament, whether nervous, sanguine, or phlegmatic. On mentioning the subject, some years ago, to Faraday, he fully coincided in that view, and expressed himself as partly subject to the same antecedent feelings as we have described. For a long time we were incredulous of the atmospheric effect resulting, previous to a storm, on beer, meat, &c.; but are compelled to admit that the incredulity was the result rather of prejudice than sound scientific induction. The year 1867 afforded, in the south of England, ample opportunity to examine the facts of the case; and, against all preconceived notions, we feel it necessary to own, that the condition of the atmosphere, in an electrical point of view, has effects on the nervous, muscular, and chemical relations of animals and plants, sufficient to place all in abnormal circumstances, and to produce consequent results in each department of organisation or existence.

The subject will commend itself as of much practical interest to many of our readers; but we forbear pursuing it further, because, like subjects of a metaphysical character, it can only be determined by individual experience and opinion, rather than by direct experimental evidence.

We have omitted to notice some ordinary class experiments in reference to the spark; as, for example, placing persons on a stool insulated by glass legs, and taking sparks from them; together with many other experiments that, whilst of an amusing character, have a less philosophic interest than those that have been adduced. We next turn to the—

Calorific Effects of Frictional Electricity.—In this respect, frictional electricity is much inferior to voltaic electricity; and we add, that the latter equally, or even to a larger extent, exceeds, in beauty and brilliancy, the luminous effects of electricity produced by friction. The phenomena of the latter form of electric force are all instantaneous in their results; so much so, indeed, that the eye has not time to appreciate such phenomena before they are entirely lost to the senses.

We will first take a very simple instance, which at once shows the rapidity of the frictional-electrical discharge, together with mechanical and calorific effects. If a little gunpowder, in grains, be distributed on a plate, and an electric discharge be passed

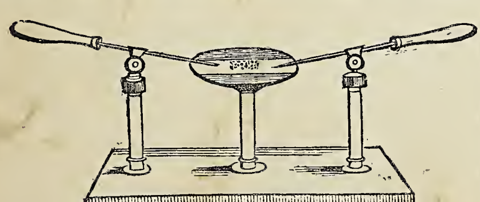


Fig. 118.—Speed of the Discharge.

through it by means of a *metal wire* attached to the inside of the jars, and to one of the handles of the discharger, whilst the other handle is connected, by means of a wire, with the exterior of the jars of the battery (a single jar will suffice), instead of the powder being inflamed, it will be only scattered about in all directions. If, however, the handle of the discharger be connected with the inside of the jars by means of a piece of wet string, the charge, in its passage, will inflame the powder. From this we gather that the passage of frictional electricity, in an accumulated condition, is so rapid between two good conductors not far distant, that it has not time to communicate its full and proper calorific effects. Hence, when the points of the handles of the dischargers are immersed in the grains of gunpowder, the handles being connected with the battery by means of metallic conductors, the effects of the discharge are simply mechanical: but a retardation of the progress of the discharge is at once attended with calorific results. Dr. Scoffern very ably illustrates this. He says, by way of explaining the anomaly—"It is not easy to ignite gunpowder by rapidly passing over its surface a jet of burning coal-gas, a certain appreciable lingering of the flame being necessary to ensure the positive result. A more striking illustration is, however, afforded by the following experiment:—On a sheet of writing-paper lay a few grains of fulminating mercury, in the form of a train; cross this train with another of gunpowder, and ignite the first. The flame passes with inconceivable rapidity from one end of the fulminating mercury to the other, the gunpowder being necessarily crossed by the line of fire; nevertheless, the gunpowder itself does not inflame. Another illustration of the same fact is this:—If a percussion-cap, the charge of which is fulminating mercury, be placed on the nipple of a very short-barrelled pistol, a charge of powder being put into the barrel, but with no wadding, and the cap be exploded, the gunpowder does not inflame. If the wadding be rammed down, or if the barrel be prolonged, then the gunpowder is inflamed, because the blast of the percussion-cap is made to linger amongst the particles of the gunpowder—in the one case by reason of the superimposed wadding, and in the other by reason of the presence of a column of atmospheric air."

Another singular circumstance, in regard to the calorific effects of lightning, is, that partial or superficial fusion of metallic bodies takes place without even singeing adjacent or animal substances. Some years ago, we saw the watch-pocket in the dress of a man injured by lightning, which, whilst the surface of a silver watch was fused, the linen of the pocket in which the watch rested showed not the slightest signs of being singed or burnt. The same circumstance came under our notice in another instance. Two persons had taken shelter beneath a tall tree during a thunder-storm. To maintain the popular phraseology, the tree and the persons under it were "struck with lightning." The heels of the boots of each person were torn off the sole wherever iron nails had been inserted. The metal of the latter was, at the same time,

fused ; but not the least sign of ignition or burning was evidenced on any part of the leather.

A common class experiment affords occasionally the same results. In the following cut, *a b c*,

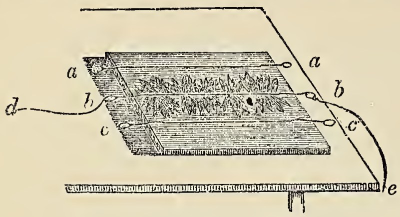


Fig. 119.

on each side, represent the ends of a strip of fine metal foil—say half an inch wide—pasted on paper, and allowed to dry. At either of these extremities a brass knob is placed. The charge of a Leyden battery is communicated, in the usual manner, at *d*, from the interior of the jars, whilst their exterior is connected with the arrangement by a wire, *e*. Fine wires may be extended between *a a*, *b b*, and *c c*, with precisely similar results as those afforded by the foil. Now, in the majority of cases, the wire and foil will be instantly ignited by the discharge, and the paper will be stained with brush-like marks, as shown in the centre of the cut. But occasionally, although even steel wire be fused under such circumstances, it will not mark the paper in the least degree ; the fused wire will fly off in globules in all directions ; but no burning or any other effect of combustion will be seen on the paper.

The experiment in reference to the ignition of gunpowder, previously named, may be carried out as represented in the following cut. *a a*

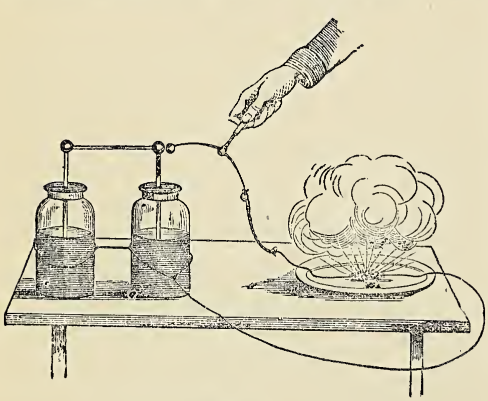


Fig. 120.

represent two Leyden jars, connected, as regards the insides, by a rod, *b* being a wire encircling both, and terminating in contact with gunpowder held in a dish, *c ; d* is the discharger, held in the hand by the glass handle (see *ante*, p. 191) ; *e* being a piece of wet string, already referred to. On the knob of the discharger being brought into contact with the knobs of the charged jars, the discharge will take place through the wetted string, at the end of which should be a small piece of wire resting in the gunpowder : the latter will thus be inflamed.

One of the most beautiful effects of electricity, as producing heat, is that by causing the discharge to pass through fine steel wire. For this purpose the wire should be attached to one branch of the discharger, illustrated at p 191, *ante*, Fig. 110 ; and the end of the fine wire should be connected, by a thick copper wire, with the earth, or a gas or water-pipe. The other knob, or branch, of the discharger is then to be brought into contact with the knob, connecting a large and well-charged Leyden battery. Instant deflagration of the wire will take place, accompanied by a shower of globules of the melted metal, that coruscate with the utmost brilliancy as they fall to the ground. The effects produced by the ten-feet plate machine, already described at p. 182, *ante*, as also of the hydro-electric machine, were of the most beautiful kind, in reference to the deflagration of wires, by this method.

The intense heat generated by any form of electric current on metallic conductors generally—nay, we may say always—leads to their oxidation as the particles of the metal become dispersed. Thus silver and gold wires, deflagrated by the apparatus already described, and illustrated by Fig. 119, always, when they stain the paper, do so by being converted into their oxides. Hence the intense heat of the voltaic discharge, called the disruptive discharge, that takes place in air, between two metallic surfaces or points, has a similar effect. Fumes of oxides escape from metals that can be oxidised by no other means of artificial heat ; for gold, silver, and platina may be kept melted, at the highest temperature, less than that afforded by electricity, without oxidation.

Many curious speculations have been made as to the cause of the luminous and calorific effects of any and every form of free electricity. In all cases, however, we may conclude that *resistance* to the passage of the force is the inducing cause of both classes of phenomena. It is familiarly known, that a solid, large conductor, if continuous, does not become heated even by the most powerful flash of lightning ; and in our laboratories and lecture-rooms, we equally find, that just in proportion as we increase the quantity and intensity of an electric current acting on a feeble conducting material, and also just as we diminish the capacity of the latter to conduct the force, so the amount of light and heat (with which we may also include that of mechanical disruptive force) is increased. Hence the violent effects of the thunder-storm, as evidenced in its passage over, or by means of, bad or imperfect conductors. This we have already alluded to, somewhat extendedly, at p. 197, *ante*.

A considerable variety of methods, other than those already described, has been used for illustrating the calorific effects of the electric current or force, as generated by friction ; but a sufficient number of illustrations has been afforded to show the nature of those effects.

We therefore pass on to consider, in the next place, the—

Mechanical Effects of Electricity, generated by Friction, or in Nature.—These mechanical effects are always found to be subject, as regards their amount, to the quantity and intensity of the free force in operation; and some most interesting results arise from the observation of such effects in nature, and also in their repetition, on the much smaller scale, by electrical apparatus.

Mechanical disruption of a body too small to carry a powerful discharge, invariably accompanies the exhibition of the luminous and calorific effects of electricity. The ignition and dispersion of metallic foil or wire, as illustrated at p. 198, and Fig. 119, *ante*, is an instance of the kind. In the voltaic disruptive discharge precisely the same thing occurs. Portions of matter travel from one point to another; and so the mechanical constitution of the body under experiment becomes affected.

Commencing the illustration of our subject on the small scale, we may suggest the following as a ready method of showing the mechanical

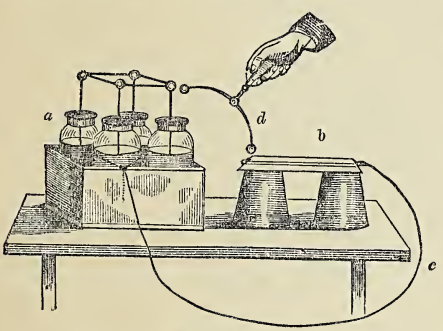


Fig. 121.

power of a strong discharge from a Leyden battery. *a* is a battery of four jars, which should be charged as highly as possible, in the usual manner; *b* consists of two plates of window-glass, enclosing between them a thin strip of gold leaf, extending a little beyond the extremities of the plates, which may be about six inches long, and two inches wide. A wire, *c*, connects the exterior of all the jars with one end of the strip of gold leaf; whilst, by the discharger, *d*, connection is made between the interior of the jars and the leaf. The discharge passing along the leaf, if sufficiently powerful, will have so great a mechanical force as to break the strips of glass into minute fragments, and force the gold leaf into its surface. With a powerful battery the effects are surprising. Here we may caution the experimenter to keep at a respectful distance from the glass; and for this purpose it is advisable to use a discharger with a very long handle, or else to employ that described at p. 192, and illustrated by Fig. 112 by which the discharge is effected spontaneously, permitting the operator to retire to any safe distance, and without the necessity of his in any way assisting.

With a powerful voltaic battery of 100 large cells of Grove's platina and nitric acid arrangement, the large blade of a common penknife may, almost instantaneously, be dispersed into vapour; but the voltaic current effects also depend on the evolution of an enormous amount of heat, which greatly tends towards the result, as additive to the mechanical disruptive power.

In the results of the experiments in breaking glass by frictional electricity, as accumulated in the Leyden battery, some singular effects are produced. The glass becomes divided into fragments, the edges of which are sharper than those of the best lancet; and should they strike the face, or any other exposed parts of the body, cause unpleasant wounds, that are generally attended with much bleeding. It is by no means an uncommon result of an electric discharge to split resisting matter into very minute fragments. Some years ago we met with a remarkable instance of the kind. A flagstaff, elevated about twenty feet above the roof of a tavern, was "struck" during a violent thunderstorm. On examining it, we found that every part of the wood was split into fine fibres, the edges of which were so sharp as to prick the hand if brought in contact with them. This result we ascribed to the expansive power which the electric force had exerted on the moisture in the wood, possibly converting it into high-tension steam, that thus drove asunder the mass of the wood; and probably the force, also, exerted its own mechanical force, in addition to this, in a manner similar to that described in connection with the experiments on the glass strips with the interjacent slip of gold leaf.

Frequently trees present a precisely similar appearance after having been "struck" with lightning. The edges of the fractured parts are invariably jagged, and usually very sharp; and this suggests some experiments that illustrate more fully the peculiarity of the mechanical effects of electricity.

If a few sheets of paper, or a thin book (both first carefully dried), be placed between the points (not the knobs) of the discharger—represented at p. 191, *ante*, by Fig. 111, or, in a subsequent page, by Fig. 118—and the discharge of a battery be passed then through them, the paper will be perforated by a conical hole, wider at one end than at the other, whilst the edges of the perforation will be driven outwards. A piece of loaf-sugar, similarly placed between the pointed ends of the handles of the discharger, and resting on the table, will be broken to pieces, and, at the same time, exhibit considerable phosphorescence.

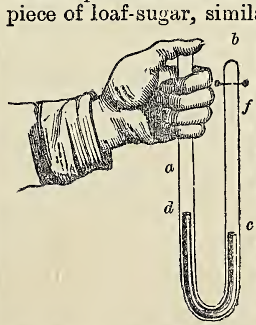


Fig. 122.—The Eudiometer.

Closely connected with all the preceding effects of frictional electricity, is a method adopted by the practical chemist—of igniting mixtures of various gases with oxygen. The instrument employed is called the

eudiometer. It has various forms; but a useful one is represented in the preceding cut. *a* is a glass tube, containing, between *b* and *c*, the mixed gases to be operated on; *c* to *d* represents some mercury; the space between the surface of the metal and the top of the left-hand leg of the vessel being kept filled with air, so as that the latter may act as a kind of cushion to diminish the violence of the explosion. The top of the left leg is closed by the thumb of the left hand. If a charged Leyden jar be held by the right hand, and its knob is approached to the end of a platina wire, *f*, a spark will pass between that wire and one placed opposite to it, terminating externally, near the knuckle of the operator. This spark at once ignites the mixed gases, causing the union of the oxygen with any hydrogen, &c., present in the right-hand leg of the eudiometer.

Instead of charging the jar for this purpose, by means of the electrical machine, recourse is generally had to the electrophorus, already described at p.182, *ante.* The instructions there given in respect to the excitation of that in-

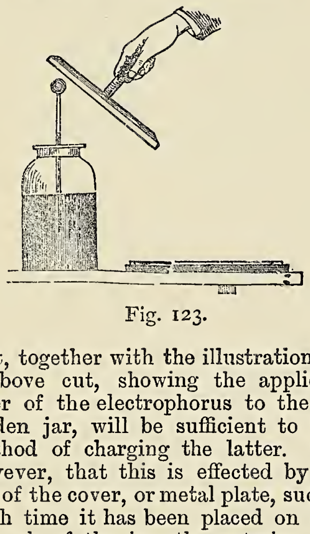


Fig. 123.

strument, together with the illustration afforded in the above cut, showing the application of the cover of the electrophorus to the knob of the Leyden jar, will be sufficient to illustrate this method of charging the latter. We may add, however, that this is effected by applying the edge of the cover, or metal plate, successively after each time it has been placed on the sole, to the knob of the jar, the exterior of which should either be held in the hand, or connected with some good conductor, as the earth, &c., by means of a wire.

The consideration of the luminous, calorific, and mechanical power of frictional or highly intense electricity, leads us to a corollary found in the principles of the lightning conductor, that is now almost universally employed for the protection of high buildings.

We have already intimated that to Franklin belongs the merit of having first pointed out the identity between the cause of the thunder-storm, and that of the electricity that we generate or set free, on the small scale, by the various forms of the electrical machine. About the years 1744 or 1746, he was the first to obtain, by means of the boy's kite, electricity in a free state from the higher regions of the atmosphere, taking a spark from the string of the kite held by a silk handkerchief. To him we are indebted, therefore, for the discovery of the lightning rod, or conductor; but chiefly to the late Sir William Snow Harris is due the merit of so far studying the principles of its construction, as to make its universal adoption on ship-board, for the masts of vessels, and a high building, a matter of precaution, now of such common use.

We have already stated, that, for the sake of simplicity, popular terms have hitherto been employed in this work, in relation to all electric phenomena; for it is desirable to familiarise the stranger to science with the latter in relation to the *facts* first, and to enter into the theory afterwards, when sufficient elementary knowledge has been obtained to make the latter understood. Nevertheless, we have shown that a lightning conductor does *not attract* lightning, but simply affords a means of its passage to or from the ground—more correctly, being a means for electrical conduction and induction.

Let us first explain the analogy that subsists between a charged Leyden jar and the circumstances of the thunder-storm. In the ordinary method of charging the jar, by means of presenting its knob to the prime conductor of the electrical machine, the inner surface of the jar becomes charged with positive electricity, and the outside to an equally exalted state by negative electricity. On the knobs of the discharger represented by Fig. 111, at p. 191, *ante,* being presented simultaneously to the knob of the interior and the coating of the exterior of the jar, a spark passes, accompanied with a report, and the electric equilibrium is at once restored.

Now the office of the lightning conductor is precisely similar to that of the discharger in the preceding experiment. It affords a passage between the clouds and the earth, by which electrical conduction and induction can be effected. It matters not whether the clouds be positively or negatively electrified (although the former case is by far the most common); for just previous to the flash of lightning, the earth must necessarily be in an opposite electrical state to that of the cloud. If no conductor be present, a spontaneous discharge, precisely analogous to that described as occasionally occurring with the Leyden jar, takes place (see *ante,* p.189). If, on the contrary, a lightning conductor be present, then the discharge prefers the shortest and best-conducting medium, and no violent mechanical or other effect is produced. Again, in the absence of the conductor, the latter occur in a manner precisely similar to the effect of breaking a jar by spontaneous discharge, in the way described at p. 189, as resulting from an over-charge produced in a jar by the hydro-electric or any other electrical machine.

In a subsequent page, we shall have to enter more into the laws that govern the uses of lightning conductors, as enunciated by Faraday and other eminent philosophers. We shall here, therefore, deal chiefly with some of the most prominent points of importance.

A great error, at the early outset of using lightning conductors, arose from the supposition that a metallic rod, elevated with a pointed

surface above the highest part of any building, &c., and carried continuously to the earth, was sufficient to protect the erection on all sides or parts. The error of such a theory exists in the fact, that every piece of metallic matter attached to, or separated from, the conductor, undergoes a precisely similar effect to that it is subject to. Thus we will suppose the case of a steeple having a lightning conductor, but the stones of which it is built are fastened together by iron clamps, or other such means. Should the conductor be struck, all the metallic objects near it tend to conduct the electricity; and if they are not in contact with it, the destruction of such parts of the erection will most likely be effected. For the same reason, the best form of lightning conductor attached to one mast of a ship, will not protect the other masts. The reason of this, and its effects, are amply illustrated in the following engraving, representing a house provided with a conductor, A, running to the *surface* of the ground by *n*. Now, supposing B to be a water-pipe running from the roof of the house into a drain in the ground, it is far more than probable that what is called a lateral discharge will take place if A be struck; that is, the discharge will divide itself, partly passing down from A by *n* to the ground, and, in part, passing from *n* to some point in B, in or out of the house, causing either mechanical disturbance, or, possibly, setting the house on fire. It is therefore essential for absolute safety, in using such a conductor, first, that it extend above any adjacent object; secondly, that it be in contact with all external masses of metal; and, lastly, that it run well into the ground at some part where the latter is constantly moist. This point may be further urged and illustrated by our stating, that, when experimenting with the hydro-electric machine described at p.185, *ante*, in very dry weather, and connecting the outside of the Leyden battery with the gas-pipes of the institution, we have known sparks taken from the pipes employed in the open street, 500 feet from the machine, although those pipes traversed under-ground, and were connected with the street lamp-posts.

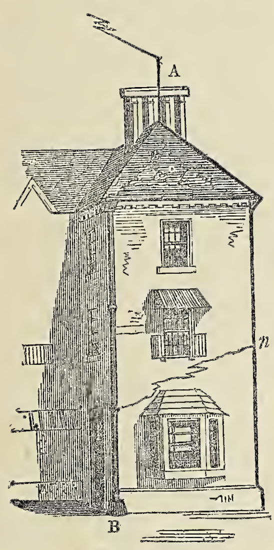


Fig. 124.

Some very interesting results were published, a short time ago, in the *Proceedings of the American Philosophical Society*, in which the celebrated philosopher, Professor Henry, described a method by which houses having metallic roofs, may be, in a simple manner, freed from any danger by lightning.

On the principle of electrical induction, houses thus covered are more liable to be struck than those furnished either with slate or tile. Fortunately, however, they admit of very simple means of perfect protection. It is evident, from well-established principles of electric action, that if the outside of a house were encased entirely in a coating of metal, the most violent discharge which might fall upon it from the clouds, would pass silently to the earth, without damaging the house or endangering the inmates. It is also evident that, if the house be merely covered with a roof of metal, without projecting chimneys, and that this were put into metallic connection with the ground, the building would be perfectly protected. To make a protection, therefore, of this kind, the professor advises that the metallic roof be placed in connection with the ground by means of metal conductors, which serve to lead the water from the roof to the earth. For this purpose it is sufficient to solder to the lower end of the gutter a riband of sheet copper, two or three inches wide, surrounding it with charcoal, and continuing it out from the house until it terminate in moist ground. The upper ends of these gutters are generally soldered to the roof; but if they are not in metallic contact, the two should be joined by a slip of sheet copper. The only part of the house unprotected by this arrangement would be the chimneys; and, in order to secure them, it could only be necessary to erect a short rod against the chimney, soldered at its lower end to the metal of the roof, and extending sixteen to twenty inches above the top of the flue.

This method was suggested several years ago, and before zinc had come into such extensive use for making roofs, gutters, water-pipes, &c. At the present day, when metal water-pipes are almost universally used to conduct water from a roof, although the latter be not made of metal, a modification of the plan just suggested could be easily made, by putting a few slips of metal soldered together to form a conducting surface on the roof, and to be attached to the gutter and water-pipe by soldering, as well as to the metallic slips already suggested as applicable to the protection of the chimneys—all the metals being carefully soldered together to make a continuous conductor.

The following account of the results that occurred to a house that had been struck by lightning, are interesting, and, in part, illustrates what has already been stated.

The lightning struck the top of the chimney, passed down the interior of the flue to a point opposite a mass of iron placed on the floor of the garret (see our remarks on such a possible circumstance, at p.177, *ante*), where it pierced the chimney; thence it passed explosively, breaking the plaster, into a bed-room below, where it came in contact with a copper bell-wire, and passed along this horizontally and quietly for about six feet; thence it leaped explosively through the air by a distance of

about ten feet, through a dormer window, breaking the sash, and scattering the fragments across the street. It was evidently attracted to this point by the upper end of a perpendicular gutter, which was near the window. It passed silently down the gutter, exhibiting scarcely any mark of its passage until it arrived at the termination, about a foot from the ground. Here, again, an explosion appears to have taken place, since the windows of the cellar were broken. A bed, in which a man was sleeping at the time, was situated against the wall, immediately under the bell-wire ; and although his body was parallel to the wire, and not distant from it more than four feet, he was not only uninjured, but not sensibly affected. The size of the hole in the chimney, and the fact that the lightning passed along the upper wire without melting it, show that the discharge was a small one ; and yet the mechanical effects in breaking the plaster, and projecting the window-frame across the street, were astonishingly great. These effects Dr. Henry attributed to a sudden repulsive energy or expansive force developed in the air along the path of the discharge. Indeed, he conceived that most of the mechanical effects which are often witnessed in cases of buildings struck by lightning, may be referred to the same cause. In the case of a house struck within a few miles of Princeton, the discharge entered the chimney, burst open the flue, and passed along the cockloft to the other end of the house ; and such was the explosive force in this confined space, that nearly the whole roof was blown off.

The peculiar class of mechanical effects here alluded to, are commonly illustrated, at the lecture-table, by an apparatus shown in the annexed cut. *a b c*, in No. 1 and No. 2, is a piece of mahogany intended to represent the gable end of a house. In the centre, *d*, of each is a loose, square piece of wood, having a strip of tin-foil pasted across it. Now, if a discharge from a Leyden jar be sent from *a* to *c*, in No. 1, the conducting strip being continuous along the whole length of the wood, the electricity will pass off quietly to the other by *c*. But in No. 2, it will be seen that the square piece of wood has been turned round, so that the continuity of the tin strip between *a* and *c* is broken at *d*. If a discharge be, therefore, passed down No. 2, instead of running off harmlessly to the earth, it will propel the square, *d*, violently from the apparatus in precisely a similar manner to that related by Dr. Henry, just previously, in regard to the window-sash being projected into the street from the house struck with lightning.

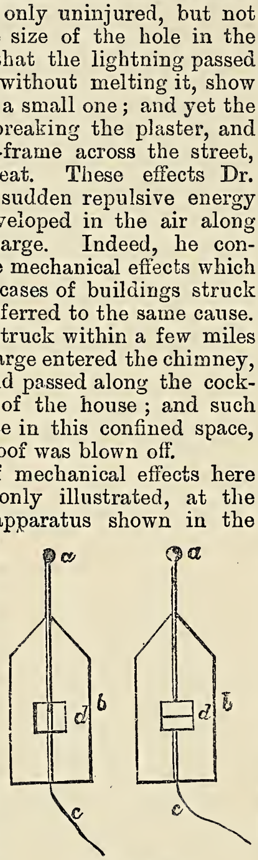


Fig. 125.

Respecting the noise which we call *thunder*, much misapprehension popularly prevails, and, apparently, the accordance or analogy between the discharge and snap, or report, of the Leyden jar with the flash of lightning and thunder here fails ; but such is not the case. In nature, as with the Leyden jar, only a single report occurs for each flash. But the clouds overhead, and the earth beneath them, act like two walls, between which the single report becomes re-echoed for periods of various lengths of time, the latter being generally much over-estimated by inexperienced observers. For the information of the latter, we relate two instances, illustrating the truth of the preceding remarks, that have come under our own notice—the first proving that only one report occurs for each flash ; and the second, that the rolling effect of that report is simply due to echo.

Some years ago, whilst ascending a hill above 4,000 feet high, in the west of Scotland, we encountered, at a height of about 1,500 feet, a violent storm of wind and rain, that suddenly came on. Before commencing the ascent, the weather was fine overhead, and indicated not the least sign of a coming storm ; but in the district to which we refer, storms often come on without any warning. Having attained the summit of the hill, the Atlantic and Irish coast were perfectly clear from any haze ; but we noticed one gradually forming beneath our feet. Occasionally we heard dull reports occurring at intervals, and *singly*, which we ascribed to the discharge of a cannon—a circumstance that was impossible, as we afterwards found, from none being kept in the neighbourhood. On arriving again at the foot of the hill, the cause of these single recurring reports was at once explained. We had been about 2,000 feet above a thunder-storm that had visited the village at the foot of the hill ; and what we had heard at the top was simply the separate report of each flash, that, heard below, was thunder in its usual rolling nature. The absence of any cloud-wall *above* the storm, and its presence below, thus at once explains our preceding remark.

In reference to the rolling sound of thunder, the following will be sufficiently illustrative :—Standing, on one occasion, on the beach near Ryde, in the Isle of Wight, we watched the commencement of gunnery practice on a ship moored off Portsmouth, or rather Southsea, on the opposite coast. At the moment the sky overhead was obscured by a thick haze, that was not more than one or two hundred feet above the intervening sea. Shortly after the smoke of each discharge was seen, the sound came *rolling* in successive waves of sound, precisely in the manner of thunder—an effect easily illustrated by throwing a stone into a still pond, when a series of waves are successively perceived. After a short time, however, the atmosphere cleared, and a beautiful morning resulted. On this occurring, all rolling of sound ceased, and a loud single report was alone heard at each discharge of the gun.

From these two simple illustrations may be learned the cause of the single noise of thunder, and also that of its rolling. Perhaps few of our readers will ever be so placed as to be *above* a thunder-storm to verify the first statement we

have made; but, within two or three miles of any naval or artillery practice, the effect of cloud overhead in producing the rolling sound, or the absence of it under a clear sky, may be commonly noticed by those interested in this subject.

Still writing on the elementary part of electrical science, we may, for a moment, confute the common supposition that the marks on the bodies of persons struck with lightning are caused by impressions of leaves of trees, as often supposed, or by other adjacent objects. Fancy lends a wonderful charm to such supposed results, that, however, have not the least to do with the supposed causes here mentioned. Particles of matter, newly arranged in position, frequently take up forms exactly similar to objects in nature; and here we can illustrate this fact, that may be readily verified by any one who has the courage to perform the following experiment:—On one occasion, especially, we noticed a singular result. Lecturing on the effects of heat, we illustrated the production of the spheroidal state of water that occurs when that liquid comes in contact with a red-hot body—or rather *not* in contact, because a kind of repulsion occurs between the red-hot metal and the water. To show this, after washing the hands in dilute ammonia, we removed from a ladle, by the naked hand, several pounds of red-hot lead, throwing the latter into a tub of water. On lifting out the solidified metal, one piece had taken a shape so exactly like a large cabbage-leaf as to be a complete copy of it in every respect. We mention this as the most remarkable instance that we have met with, but have seen scores of others of a less complete kind. Now, this result could only arise from an accidental assumption of the form of the leaf, due to a new arrangement of the particles of the lead. In precisely a similar way the marks of leaves, &c., on bodies can be accounted for.

It may be naturally expected that we should make some remarks on the danger possible in thunder-storms, and give hints as to the most probable means of safety.

At p. 201, *ante*, we have shown that a house with a metallic roof connected with a metal water-pipe, the latter resting in the drain or damp earth, may be rendered absolutely lightning-proof; and the most severe storm that can occur would pass harmlessly by, even if the lightning struck the house. The safety of such a house would depend on all the metallic connections being made complete by either soldering or riveting. Hence those of our readers who may be alarmed at the thunder-storm, can, by following the instructions given at the page just referred to, render themselves perfectly free from danger.

But the greater proportion of houses have tile or slate roofs. Now the first object that the lightning would strike would be the chimney-pot, especially if it be a metallic one. The soot of the flue, together with any warm air in it, would both act sufficiently conductive to permit of the passage of the "electric fluid" into the house. Leaping from the grate, it would then extend, as already shown, to any metallic conducting body in the room. Common sense, therefore, suggests that the wisest course is to keep away from all good conductors—such as the grate, fire-irons, bell-wires, and, indeed, everything of a metallic nature. But an anomaly might present itself—presuming two persons sleeping respectively in an iron and a wooden bedstead in the same room, and that both be struck, the one in the iron bedstead would almost certainly escape unhurt; whilst the probability is, that he sleeping in the wooden bedstead, the parts of which would most likely be connected with metal screws, &c., would be thrown out by the destruction of the bedstead, and, sleeping amongst a lot of good and bad conductors, might receive serious, if not fatal, injury. An accident of this kind occurred in 1867, during one of the numerous storms that visited our islands in that year. In the bedroom of a house struck by a powerful flash, the parents, sleeping in an iron bedstead, escaped unhurt; whilst a cot adjacent to it, made of wood, was shivered to pieces, and the child it contained was killed. The bell-wires, in this instance, were insufficient to carry off the charge, and, consequently, the house was set on fire in two places where the metallic communication became destroyed by the melting of the wires.

In the open air, nothing is more dangerous than to stand under trees during a thunderstorm. In nearly every case they are higher than any other adjacent object; and even if lower, they are far more likely to be struck than a building, because the shape of their twigs, branches, and leaves, is just that which would favour their acting as conductors. The danger is still greater if shelter be taken before rain has wetted the entire tree; and, generally, persons run under it at the commencement of the thunder-shower. If every part of the tree become perfectly wetted, it is then converted into a tolerably good conductor, and the danger is lessened; hence the persistence in a practice that is so dangerous, because, through the cause just named, so many trees escape being struck in the most violent thunder-storm. A curious fact that we have noticed for many years past, is, that trees, at a comparatively high eminence above a plain, are less commonly struck than those lower down; and that, in a hilly country, it is a rare sight to meet with a tree so destroyed; whilst in levels or hollows the occurrence is common. Again, we have noticed that thunder-storms are most prevalent and violent in damp, marshy, undrained districts, than in those of an opposite character. Our observations have, in this respect, been entirely confined to our own islands, but in all parts of them; yet it is possible that the rule may not be universal. Should these statements be perused by scientific individuals resident in hot climates, where thunder-storms are much more common and terrific in their results than in our country, it would be worth their attention to verify or confute the suggestions we have made, as resulting from limited experience.

Partial safety, in an open country, can only

be insured by laying down flat on the ground, if possible, for shelter from rain, under the lee-side of a bank, without any bushes or trees growing from it. An upright position, with an umbrella overhead, especially if made with metal ribs, &c., is a condition highly fraught with danger during a violent thunder-storm. Hence it so frequently happens that cattle, sheep, and the persons tending them on plains are destroyed wholesale—the lower animals sometimes by hundreds. They are higher than the surrounding grass, and, consequently, become conspicuous objects for the electrical discharge to be carried through. Indeed, frequently they are the only raised conductors, and suffer accordingly. Throughout the greater part of western Europe, the year 1867 became marked for the number and extent of such fatal occurrences; and the very nature of the circumstances under which such take place, renders it impossible to give any directions that might conduce to safety, further than by repeating, that in respect to human beings, the only safe position is that of laying flat on the ground, and removing from the clothes, &c., any metallic object, as a watch, money, keys, and the like.

Several years ago, Mr. Crosse, the celebrated electrician, erected, in one of his fields, a number of vertical and insulated iron rods, connecting all their extremities together by one rod, and bringing the end of this into a room. The end was covered with a large brass knob, and fixed on an insulating stand. Opposite, and also insulated, was a rod connected with the earth, and ended with a knob, arranged so that it could be brought near to, or removed from, the one terminating the collecting rods in the field. By this arrangement he could produce an actual thunder-storm in the room; and the effects that he described as having witnessed, were terrifically grand, in respect to the light and sound produced. But it was not alone during a thunder-storm that such effects were witnessed. Even the passage of a kind of haze over the collecting rods, produced the same remarkable phenomena; and by continually observing these effects, he discovered that the atmosphere is frequently, if not constantly, charged with free electricity, in greatly variable degrees. Consequent on his experiments, observations are now constantly taken at some of the scientific institutions, and by private persons, on the amount of free electricity, as indicated by an electrometer; and many interesting results have been arrived at in connection with meteorological phenomena. Into these we cannot here enter, because they belong more especially to the science of meteorology. In mountainous countries, as in the Alps, the free electricity is so large in quantity, that the clothes and bodies of the travellers will give off sparks, whilst the hair of the face and head becomes repelled, to a degree creating much discomfort. A melancholy occurrence will be remembered by some of our readers, in which, owing to this, a bride was killed on the Alps, whilst visiting those mountains with her husband, during their wedding tour. The following is an interesting account of a modified form of the phenomena, as experienced by Mr. Watson on the Jungfrau, on the 10th of July, 1863.

"I visited the Col de la Jungfrau, from the Æggisch-horn, in company with my wife, and Messrs. J. W. Sowerby and W. E. Adams. * * * * The early morning was bright, and gave promise of a fine day; but as we approached the Col, clouds settled down upon it; and, on reaching it, we encountered so severe a storm of wind, snow, and hail, that we were unable to stay more than a few minutes. As we descended, the snow continued to fall so densely, that we lost our way, and for some time we were wandering up Lötsch Sattel. We had hardly discovered our mistake, when a loud peal of thunder was heard; and, shortly afterwards, I observed that a strange singing sound, like that of a kettle, was issuing from our Alpen-stocks. We halted; and, finding that all the axes and stocks emitted the same sound, stuck them into the snow. The guide now pulled off his cap, shouting that his head burned; and his hair was seen to have a similar appearance to that which it would have presented had he been on an insulated stool, in connection with a powerful electrical machine. We all of us experienced the sensation of pricking or burning in some part of the body, more especially on the head and face; my hair also standing on an end, in an uncomfortable, but most amusing, manner. The snow gave out a hissing noise, as though a heavy shower of hail were falling; the veil on the cap of one of our party stood upright in the air; and, on waving our hands, the singing sound issued loudly from the fingers. Whenever a peal of thunder was heard, the phenomena ceased—to be resumed, however, before its echoes had died away. At these times, we felt shocks, more or less violent, in those portions of the body which were most affected. By one of these my right arm was paralysed so completely, that I could neither raise nor use it for several minutes, until it had been severely rubbed; and I suffered much pain in it, at the shoulder-joint, for several hours. At half-past twelve the clouds began to pass away, and the phenomena finally ceased, having lasted twenty-five minutes. We saw no lightning."

The preceding graphic account presents a singular combination of nearly all the phenomena of electricity that we have yet described; and is a remarkable illustration of the identity of the electricity of the thunder-storm with that of the electrical machine.

Chemical Effects of Frictional Electricity.—The chemical effects of electricity excited by friction, afford a remarkable contrast to those that result from the action of the force as primarily excited by chemical action in the voltaic battery. In this, as in every other respect, frictional electricity is contrastive with voltaic electricity, especially in the circumstance of continuity of action. Frictional electricity does its work instantaneously; while voltaic, or chemically-excited electricity, is slow, gradual, but highly effective in its action. Many theories

have been propounded to explain or account for such difference of action; but they, hitherto, have all failed to explain such differences.

Here it will not be out of place to make some remarks on the essential difference that subsists between electricity excited by friction, and that which results from the exertion of chemical affinity.

Quantity and intensity (or tension) are two terms that have been employed to designate the difference between the supposed causes and consequent effects of electricity produced by the two methods above mentioned. By the electrical machine, whether of the cylindrical, plate, ebonite, hydro-electric, or any other form in which friction of a surface is the source of the electric force, we obtain this in such a condition that it can readily overcome the resistance afforded by aëriform bodies. For example, the spark from the prime conductor of the electrical machine passes through a considerable distance in the air—a result that has never been attained by the most powerful voltaic battery which has yet been constructed. The electric force of the latter has not the power to overcome such resistance as the air affords to the passage of the current, unless the air be highly heated; but, in the latter case, the effects are of the most magnificent kind, as shown in the disruptive discharge of the voltaic battery, popularly recognised in the electric light.

Midway between the results of the electricity developed by friction, and those afforded by the voltaic current, are some which the induction of Rhumkorf's coil produces; especially so as regards chemical and electro-magnetic results. In these respects, the electrical machine and the induction coil are all but identical.

The reason of this is, they both are capable of affording electricity of high tension, or power to overcome aërial resistance; that is, they are able to afford electricity in such a condition that the atmosphere cannot prevent the propagation of electrical induction.

But, as previously noticed, frictional electricity, and that afforded by electro-magnetic induction, have feeble effects in respect to the production of chemical decomposition. Ranking the lightning of the thunder-storm with frictionally-produced electricity, and comparing it in its chemical effects in decomposing, for example, water, a wire, each of zinc and platinum, half an inch long, immersed in a dilute solution of sulphuric acid, will evolve a greater *quantity* of electricity, so far as chemical action is concerned, than that evinced by the most powerful flash of lightning. It must be borne in mind that this is not a statement made rashly. Faraday was the first to prove this fact; and we can, without hesitation, confirm what he said; for whilst the iron of the hydro-electric machine, already described, would, if properly arranged as a voltaic battery, have produced enormous chemical results, the whole force of the instrument, when in the best condition for action, barely afforded evidence of the decomposition of water, or of metallic and other salts.

It is a remarkable fact, and one which highly characterises frictional from voltaic electricity, that whilst, in the former case, the worse the conducting power of the liquid, the greater is the effect of chemical decomposition—the greater the conducting power of a liquid exposed to the action of the voltaic current, the larger is the amount of decomposition effected. This fact will be more apparent if we state the two methods of obtaining the results alluded to. Supposing that we are desirous of decomposing water by means of the voltaic current, we add sulphuric acid to the water to make the latter a better conductor; and within a certain extent, the more acid that is added to the water, the greater is the amount of decomposition that results. Again, the larger the amount of surface of the ends or poles of the battery that are inserted in the water intended to be decomposed, the greater is the amount of the mixed gases that can be collected.

But if we wish to approximate to the same results, using, for the purpose, even the most powerful electrical machine that has yet been constructed—instead of using dilute acid, we employ *pure* water; and in place of large plates in the decomposing liquid, we are compelled to adopt wires, of which only the points are exposed. Under such circumstances, the decomposition of water, &c., may be effected; but the result is so feeble, that all we can say of it is, that it simply proves, satisfactorily, that electricity produced by friction, and the same force afforded by chemical and other means, are identical in their results on all chemical compounds.

The chemical effects of frictional electricity are therefore extremely insignificant in result. Whilst a few grains of zinc and silver, or platina, properly disposed in a voltaic arrangement, would afford the mixed oxygen and hydrogen gases resulting from the decomposition of water, at the rate of several cubic inches per minute, the ten-feet plate, or the hydro-electric machine would, in the same period, only, and by the most careful management, afford a few bubbles of the gas. This distinction between the *quantity* of the voltaic battery, and the *intensity* of frictionally-excited electricity, should be carefully remembered as being highly distinctive of the sources of the force.

Physiological Effects of Frictional Electricity.—The "electric shock" is familiarly known as a result of the physiological effects of electricity. A half-pint to a pint size Leyden jar affords a shock abundantly strong for the nerves and muscles of most ordinary persons. It is remarkable, however, how much persons differ in regard to their sensibility to the shock of a Leyden jar. The power of the shock is generally estimated by the amount of muscular contraction that it causes, rising from the wrist to the arms, shoulders, and chest; and a shock that only affects one individual below the elbow, is sufficient, in another, to cause severe pain across the chest. The weaker the person, apart from actual disease, the less is the shock felt; whilst a strong muscular man will suffer considerably from the same amount of shock. For example,

we have seen delicate females sustain a strong shock without injury, or even unpleasantness; whilst a brawny workman, and, as we saw, in one case, a railway engine-driver, almost prostrated with a shock from the same charged jar.

The cause of the electric shock, so far as the action of electricity on the human system is concerned, is, doubtless, an action on the nervous system, causing subsequent muscular contraction; and it is chiefly from the sudden exertion of the latter that the pain arises: hence we see why a muscular person should feel the shock to a greater extent than one, in that respect, physically inferior to him.

If one individual only take a shock, the jar, which should not exceed a pint in capacity, is to be held in one hand by its exterior, whilst a wire is approached, by the other hand, to the knob communicating with the interior of the jar. A better plan, and that often saves the jar being broken, if thrown down by the sudden fright of the shock, is, for the person to hold a wire in each hand, and then to touch the exterior of the jar and its knob simultaneously, when, of course, the shock will be received. If more than one person receive the shock, all should join hands together, the left hand of one joining the right hand of the other. The two individuals forming the end of the chain, holding a wire in the free hand, then touch, the one the exterior coating of a charged jar, and the other its knob, by means of the wires held. At the same instant the whole will receive the shock.

Many years ago, the value of the electrical machine, as a remedial agent, was so highly extolled, that it was considered to be a panacea for nearly every affection of the nervous and muscular systems, so far as the mutuality of affection of them was productive of disease or pain. Hence paralytic and rheumatic patients were submitted to the action of "drawing sparks from their bodies," by placing them on a stool having glass legs, so as to insulate them from the ground—a metallic rod, ending with a brass knob, being presented to the affected part by a person standing on the ground. There is no doubt that, at times, such a method may prove beneficial; but it is now rarely, if ever, adopted, because various forms of the voltaic battery, composed of alternate wires of zinc and copper, excited by a little vinegar and water, or the electro-magnetic coil machine, are far easier applied, and require little or no trouble in their use.

The particular characteristic of the shock caused by frictional electricity, is that of suddenness and violence. It lasts but an instant, yet its force is great. On the other hand, the shock from the voltaic battery, or the coil machine, is continuous, and, in the latter, of rapid succession, owing to the number of currents generated, in a definite period, by the action of the contact-breaker. The voltaic and coil machine shock, again, can be regulated with the utmost nicety in respect to the constitution of the patient, and his power of enduring it—a circumstance of the utmost importance, because the value of electricity in such cases essentially depends on a proper adjustment of the amount of force exhibited in any case whatever.

Speed of Electricity in its Passage by Conductors.—This subject is one of great difficulty to determine accurately; and, in fact, has never yet been properly accomplished. We may here briefly allude to the methods that have been adopted in measuring the rate of speed that frictional, and other forms of electric passage, require; and, to illustrate the subject, may properly avail ourselves of the analogies that other forces in nature present. The subject is intimately connected with the laws of conduction and induction; and, consequently, will incidentally receive frequent attention hereafter, when we more carefully investigate those phenomena of the force.

Taking, first, the force of gravitation, it is familiarly known, that if a body fall towards the earth, it does so at such a uniformly definite rate, that our most valuable means of regulating the speed of a clock—the pendulum—is constructed in obedience to that law, the length of the pendulum governing its number of vibrations per second of time. This, for the latitude of London, is 39·1393 inches. A body falling *in a vacuum* passes through a space of a little over sixteen feet in a second of time, no matter whether it be a feather or a piece of platina, the latter being about the heaviest body that we are acquainted with in nature. We also can ascertain, experimentally, that, at the conclusion of that period, the body will have acquired a velocity equal to a little over thirty-two feet per second. Now, so far, we can most accurately decide the force of gravitating attraction on any part of the earth's surface; for we find that the pendulum oscillates at speeds varying according to an increased or decreased distance from the centre of the earth, as at the poles or the equator, the latter being, as already shown at p. 187, *ante*, thirteen miles further from the centre of the earth than the poles. Indeed, so accurate is this measurement capable of being effected, that, at the level of the sea, the latitude of a place may be discovered by simply observing the number of oscillations of the pendulum at a given time. Again, we can control our terrestrially-obtained results by celestial observations; for just as any body on the face of our globe is attracted to its centre by the force of gravitation, so the sun attracts to itself all the planets of our system; and this force being uniform, and undergoing no alteration under identical circumstances, allows of our stating the exact place of a planet years, or even ages, before, or subsequent to, our day. Hence the prediction of an eclipse to come can always be made so accurate, that, at the lapse of years, the error between the real and predicted occurrence shall not in any case exceed a few seconds. In precisely a similar manner, other astronomical phenomena are predicted with all but absolute certainty. We thus see that one of nature's forces can be estimated and measured with an accuracy little short of absolute precision.

The consideration of cohesion and chemical attraction will not in any way assist us, because they act on matter at distances far too minute for the eye of man to appreciate.

We next, therefore, turn to sound. The rate of passage of the vibrations producing sound has been pretty accurately measured by careful experimenters. It varies according to the conducting power of the medium through which it passes; but, in still, dry air, it is estimated that sound travels at the rate of from 1,120 to 1,140 feet per second, being much more rapid in bodies of greater density, as water, metal, wood, &c.

In the passage of the vibrations of sound, we therefore find much greater rapidity than in the effects of gravitation in respect to putting matter into motion, in the proportion of 32 to 1,120, and so make a rapid leap in the rate of the passage of force when we deal with that of sound.

But the speed of the latter is as nothing compared to that of light, which is, indeed, all but inconceivable. For example, a ray of light would require only about the eighth part of a second to pass round the earth at the equator, or through a distance of 24,000 miles. If the light of the moon, which is distant from us about 230,000 miles, were suddenly eclipsed on its surface, and restored, it would only require a little over a second of time for us again to see our satellite. The rate of the passage of light has been variously estimated at from about 185,000 to 192,000 miles per second in space; but the former is the more probable rate, for reasons that will be presently explained.

To describe the terrestrial, or, more properly, our experimental means of ascertaining the velocity of light, as adopted by Wheatstone, Foucault, and other eminent investigators, would require a minute inquiry into matter that would be foreign to our subject; but that will here, in part, have to be explained presently, when we mention the means that have been tried to measure the velocity of electricity. But we may briefly mention a means that we have of controlling such results by the observation of the eclipses of Jupiter's satellites—a phenomenon of constant occurrence.

We have already pointed out, at p. 187, *ante*, that our intimate knowledge of the laws of gravitation enables us to assign the exact place of any planet, or its satellites, for any chosen moment. Hence, of course, we can accurately state the period of the eclipses of any of the bodies of our system. Having thus the power of ascertaining, at any moment, the proper position of Jupiter and his satellites, it is evident that, if the eclipses of the latter are not observed to occur at the predicted moment, some cause apart from gravitation must exist. About 200 years ago, Röemer, a Danish astronomer, was the first to point out, that when Jupiter was in opposition, the eclipses always happened earlier than the predicted time; and that when the planet was in conjunction, the eclipses happened later. Now, as, in opposition, the planet is at its least distance from us, and, when in conjunction, it is at its greatest distance, it evidently follows that *the difference of the distance* is the circumstance that accompanies the difference between the observed and assigned time of the eclipse of a satellite; whilst the *actual cause* is, that the light has further to travel in one case than in the other, and that, consequently, however rapid its flight may be, it is not only not instantaneous through such distance, but takes sufficient time to allow us to estimate the rate of its progress. Without entering into a further exposition of astronomy, suffice to say, that knowing the length of time that occurs between the real and apparent occurrence of an eclipse of a satellite of Jupiter, and also knowing the distance at opposition and conjunction that planet and its satellites have in reference to the earth, it only becomes an arithmetical question to calculate the speed of light (allowing for the motion of the earth, &c.); and we consequently arrive at the conclusion that light travels, in space, at about the rate of 185,000 miles per second of time.

There is something extremely wonderful in this; and it shows how greatly the intelligence and powers of man are extended by scientific observation and study. The experimental attempts to investigate the subject, that we were obliged to dismiss the consideration of, reflect the highest credit on the ingenuity and skill of those who engaged therein; but the results so obtained can only be considered as little better than exceedingly approximate guesses of the truth. But, as we have seen, nature affords us a field millions on millions of miles in extent, on which we can devote careful observation, whilst our means in respect to length, on earth, can hardly exceed a few miles. Thus what, at one time, puzzled early astronomers as an anomaly in nature, became, in more able hands, a method of measuring the speed of light, and also of confirming rather than impugning those laws of attraction that affect the motion of the heavenly bodies, as already frequently explained in the preceding remarks.

We have thus endeavoured to show how we measure the velocity of gravitating force, of sound, and of light; and each of these instances will aid the unscientific reader to understand the next subject that we have to deal with—namely, the measure of the speed or velocity of electricity through space, or by means of solid conductors.

Before doing this, however, we may properly enter into a brief description of a term that will subsequently be frequently used—we mean that of *Undulatory Forces.* It is used to designate all such force as seems to be propagated by undulations (Lat. *Unda*, a wave), or waves, and includes heat, light, electricity, magnetism, and sound. In regard to applying it to light, but one opinion can be held for our justly doing so; because, by means we cannot here describe, we can measure the undulations of that force with comparative ease, and all but absolute certainty. The nature of such undulations is easily illustrated by simply throwing a stone into still water, when, as is well known, a succession of waves is propagated from the point at which the stone first touched the water; and as these

waves travel they expand in increasingly large circles, until they are lost to sight. In a similar manner the waves of sound spread around its source in radial lines; and, from analogy, we conclude that heat and electricity are propagated from a centre of force to surrounding objects. In attempting to measure the speed of electricity we have many difficulties to contend with. We have not the assistance that has been described, which astronomy affords in measuring the speed of light—namely, a length of field for observation, measured by intervals of millions of miles. We can only experiment on this force by means of solid conductors of short lengths; and even in these, an interfering cause—namely, induction—prevents us obtaining accurate results. For example, taking the voltaic current in respect to the speed of its passage, we might naturally have hoped to gain some definite knowledge of the rate at which electricity travels. If the two cables of the Atlantic telegraph were joined in America, and a current be sent from Ireland, of course its effects would be evidenced at the latter station, because the current would have to travel back. But, in observing the result, instead of the effect being evident instantaneously on the instrument, it appears to drawl out, taking an appreciable length of time. This does not arise from the comparative slowness of the current in its passage, but from the inductive influence operating on the cable. It may be practically considered as a Leyden jar of enormous length, the inside wire corresponding to the inside of the Leyden jar, the gutta-percha coating to the glass of the jar, and the exterior steel wire, or the water of the ocean, to the outside coating of the Leyden jar; hence electric currents other than that sent by the battery from the station, are generated, that exercise results which prevent this method being adopted to ascertain the velocity of passage.

In experiments that we tried on a length of 950 miles of wire, the apparent speed of a voltaic current did not seem to exceed 4,000 miles per hour—a very different estimate to that made by Professor Wheatstone, which will be presently described.

About the year 1833, that philosopher turned his attention to the subject. As Dr. Scoffern observes, his reasoning was thus:—"If electricity takes time to travel, a charge transmitted through a circuit broken in two points cannot appear at both points at once. Such a conclusion necessarily follows from these premises; there is no alternative. If no distinction of time has been recognised, this circumstance may be attributable to imperfection of our means for testing the fact. Professor Wheatstone, therefore, applied himself to the discovery of more delicate methods of investigation than philosophers had hitherto employed; and, ultimately, he adopted the following happy expedient:—Several miles of insulated copper wire being wound round a disc of wood, the coils were so arranged that certain interrupted portions of them corresponded with one straight line. Now each interrupted portion would necessarily correspond with an electric spark on passing the discharge along the wire; and supposing electricity to occupy time in travelling, these sparks must occur successively. Hence the proposition resolved itself into a discovery of some means of estimating the succession. Mere chronometric observation would have been totally inadequate to this end, as previous experiments had demonstrated: some other plan was required.

"Now, instead of viewing the sparks directly, they may also be viewed as reflected by a mirror. If reflected by a mirror at rest, no point would have been gained; but provided electricity occupied time in travelling, some evidence of this might be anticipated *à priori*, by viewing the sparks as reflected by a mirror in rapid rotation; for whilst the electricity had been occupied in travelling between successive portions of the wire, the mirror would have been performing its revolutions; and having reflected one spark at a determinate angle on a certain part of the screen, it would have reflected the second spark at another angle on another part of the screen, not in the same line with the first point. Therefore, supposing the result to be as here assumed, and which is actually the case, the elements for calculating the velocity of electricity under the conditions of the experiment are supplied; the data of subsequent calculation being the length of wire between spark and spark, and the velocity of the revolving mirror. Professor Wheatstone found that the reflected sparks were no longer in the same line, but supposing them originally to have constituted a vertical arrangement ⁝, their reflected images assumed the form of a letter V (⁝·).

"This beautiful result demonstrated two points. Firstly, it demonstrated that electricity does not pass instantaneously through copper wire; secondly, it demonstrated that electricity—whatever may be its real nature—proceeds from the two extremities of a conductor towards the centre of its length: otherwise the reflections would not have assumed the form of a V, but would have appeared in a diagonal line ⋱.

"The data of this experiment enable us to arrive at the conclusion that electricity either travels through copper wire, of the diameter used, at the rate of about 300,000 miles per second, or double that rate, according as we adopt the theory of one or two electric fluids. At the lowest estimate, then, it cannot travel at a slower rate than 300,000 miles per second, whilst light travels at the rate of less than 200,000 miles in the same time."

In the preceding quotation, it will be noticed that an alternative exists as to whether we are to consider the passage of the charge as occurring right through the wire, or simultaneously from each end, and meeting in the middle. Hence the results afforded, as just described, are subject to an error of estimation, that however we may admire the ingenious manner by which they were obtained, leaves us as much in doubt as ever. The subject is one to which we shall have again to refer; and we can here only add, that analogy would lead us to esti-

mate the velocity of electricity at a much lower rate than stated by Professor Wheatstone.

Presuming the correctness of the estimate of 200,000 or 300,000 miles per second, the difficulty that we just hinted at—of a double charge occurring, one from either end of the wire—involves a consideration of the two chief theories that have been advanced to explain the nature of electricity, and that we have partly noticed in the previous pages. Franklin was of opinion that there is but one force, fluid, or current. He explained the presence of positive electricity, in a free state, to an accumulation of the force, whilst he considered negative to be a state of its absence. A charged Leyden jar, for example, he would suggest, is like a cistern full of water, replete to overflowing, and having a tendency to restore the electric equilibrium by rushing to fill the void in a negatively charged one. By such a theory, the passage of electricity is considered merely as the passage of a fluid through, or on, a suitable conductor, just as gas and water pass through pipes—an idea already mentioned at the commencement of this work, and one that even is yet, practically, countenanced in the use of the word "current."

But now, whatever phraseology is employed for the sake of making the phenomena of electricity capable of being comprehended, Du Fay's double theory is universally adopted. He suggested, that two entirely distinct electrical fluids exist—the one vitreous, as produced by the friction of glass, and the other resinous, as produced by the friction of resin-like bodies. He considered, that when a body became positively electrified, it induced an equal amount of negative electricity in another adjacent to it. Thus suppose we take the charged Leyden jar. According to Du Fay, the inside of the jar is charged, to an equal extent, with positive electricity, as the outside is with negative. Each fluid is exactly equal, in force and intensity, to the other; and when the jar is discharged, the two electricities re-combine, all free electrical manifestation is lost, and instantly the equilibrium of the two surfaces becomes restored.

We have already illustrated this view by the engravings given at p. 179, *ante*, and their study will assist the unscientific reader towards understanding a very difficult matter. We shall have to go deeply into the subject hereafter, and recount the experiments of Faraday, and other eminent philosophers, that have been made to settle the question. We shall, therefore, only add, that whilst the theory of Franklin, to some extent, explains electrical phenomena, it utterly fails in certain cases; whilst Du Fay's double theory is universally applicable, and fails in no case.

It has the additional advantage of extending the series of analogies that subsist between electricity and magnetism. If we take, for example, an ordinary bar magnet, we shall see at once a great resemblance between the action of two electric fluids and the phenomena of magnetism. As already stated, north poles, presented to each other, mutually repel, whilst a north and south pole mutually attract. So an attraction is evidenced between two dissimilarly electrified bodies, whilst those similarly electrified repel each other. Again, whilst no magnetic force is evident in the *centre* of the bar magnet, its two extremities afford an amount of force exactly equal to each other, just as, by the double theory, the positive and negative electricities, although at an opposite exalted state, exactly equal each other.

It is true that such a theory has no parallel, in regard to forces in nature, beyond electricity and magnetism; whilst, however, a slight analogy creeps in by way of opposition. Thus, in respect to light, we notice its presence, *light*, opposed to its absence, *darkness*. In regard to gravitation, we have the oppositions of *rest* and *motion*. In chemistry, there are the *quiescence* and *activity* of affinity; and, in regard to cohesion, we have *resistance* to mechanical force, excited on a mass, as of iron, and an almost *absence of resistance* in soft bodies, such as chalk. But all these apparent analogies not only prove nothing, but have no relation to the peculiarities of electric and magnetic forces; for in all these developments they differ from other forces in innumerable points, although occasionally—as, for example, in the phenomena of attraction—electricity and magnetism are like to gravitation, cohesion, and chemical attraction.

Before concluding these preliminary views of different departments of the science of electricity, we may notice that some animals are the source of the force; apparently the result of nervous action, and under voluntary control. The chief are the following:—

The Electrical Eel (Fig. 126)—*Gymnotus electricus*, belonging to the family *Gymnotidæ*, of the order *Physostomata* of fishes—is very remarkable for its production of electricity. It is a native of marshy places in South America. "This fish possesses a most wonderful power of communicating an electrical shock to anything with which it comes in contact; and this is said to be sufficiently strong to knock down a man, and deprive him of the use of a limb for several hours." If such be really the case, these eels must have much greater power in their own country than when experimented on here; for we have frequently taken shocks from the electrical eel that was formerly at the Adelaide Gallery, in the Strand, and never judged such shocks to exceed in intensity those of a fully charged Leyden jar. The eel to which we refer was the subject of very interesting investigation by Faraday. But to continue Mr. Dallas's description:—"The electrical eels attain a length of

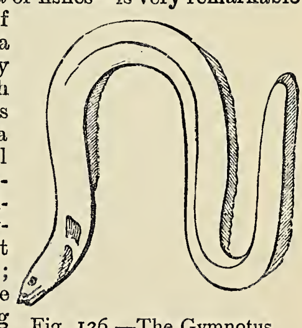


Fig. 126.—The Gymnotus.

five or six feet; and as the apparatus from which the electricity is evolved extends throughout the greater part of the body, it may be readily imagined that the discharge of such a battery must be a formidable affair. The apparatus (see annexed cut) is composed of four longitudinal bundles, placed on each side of the dorsal, and one on each side of the ventral region of the body. These bundles are composed of a multitude of horizontal parallel plates; the quadrangular canals thus formed being filled with a gelatinous matter. The whole apparatus is liberally supplied with nerves, and may be considered to represent an exceedingly complicated galvanic battery. So powerful, in fact, is the current of electricity evolved by it, that it can decompose chemical compounds, and magnetise steel needles. It appears that the anterior portion of the apparatus is positive, and the posterior negative; and that those parts of it only which are in contact with an object are implicated in the production of the current. Nevertheless, it is said that the animal can make use of it in benumbing small fishes at some distance from it in the water. The Indians of South America, when they wish to capture this fish, commence their operations by driving a number of horses and mules into the ponds inhabited by them; the eel, alarmed at the disturbance, immediately attacks the intruders upon their quiet domain, usually applying their entire length to the bellies of the unfortunate quadrupeds, and then giving the full effect of the whole electrical apparatus. Some of the horses soon become disabled, and, falling down in the water, are drowned; the others, being driven back by the shouts and whips of the Indians, continue the conflict until the powers of the *Gymnoti* are for the time exhausted. These then endeavour to escape from the scene of warfare, and, for this purpose, approach the shore, where another enemy awaits them: the Indians, armed with harpoons attached to long cords, strike at all that come within reach; and, by jerking them rapidly out of the water, so as to keep the cord from getting wet, continue to secure their booty without receiving a shock. Several other species of this family are found in the waters of South America, but none of them appear to possess electrical powers."

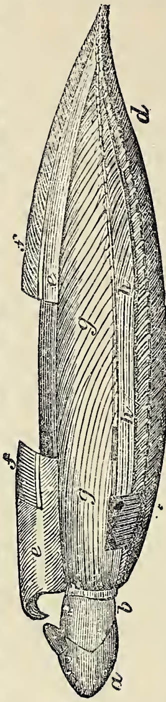


Fig. 127.

In the above, *a* represents the head; *b*, the cavity of the body; *d d*, the ventral fin; *e e*, the skin; *f f*, the muscles of the fin; *g g*, the electrical organ; and *h h*, the smaller organ.

A species of *Siluridæ*, the *Silurus electricus*, or *Malapterurus electricus*, is a small fish, from twelve to fifteen inches in length—a native of the rivers of Africa, and possessing electrical powers, but in an inferior degree to the gymnotus.

The Torpedo, or Electrical Ray, belongs to a family allied to the common Ray, and named the *Torpedinidæ*. They are "distinguished by their rounded smooth bodies, and by the possession of electrical apparatus. The latter is disposed in two masses, one on each side of the skull, occupying the space between that capsule and the base of the pectoral fin. It is composed of a multitude of perpendicular gelatinous columns, separated by membranous partitions, which receive an immense number of fine nervous threads, derived from the eighth pair of nerves, or *nervi vagi*. Nearly twenty species of this singular family are known; they inhabit the seas of all parts of the world; and all, probably, possess electrical powers. Two or three species are found in the European seas, especially in the Mediterranean; and one or two of these have occurred on the British coasts; but there appears to be some doubt as to the actual species taken by our fishermen. The electrical powers of the torpedo were well known to the ancients; and, as long ago as the time of Dioscorides, the shock communicated by this fish was recommended for medical purposes, and especially for pains in the head. This may be considered as the earliest record of the application of electricity to medicine. In later times, it was applied to the cure of the gout, the patient being directed to keep his foot on the fish until the numbness extended to the knees (*Yarrell*). The real object of the electrical powers with which this, and a few other fishes, are endowed, is not very clearly ascertained; and we can only judge, from probability, that this property is given them partly for their protection from danger, and partly to enable them to obtain food. This latter office is probably one of great importance to the torpedo, which is exceedingly slow in its movements. Mr. Couch also thinks that the electricity of this animal may have some influence upon the digestibility of the animals killed by it, rendering them 'more readily disposed to pass into a state of decomposition, in which condition the digestive powers more speedily act upon them.' He adds—'If any creature, more than others, might seem to require such a preparation of its food, it is the cramp-ray, the whole canal of whose intestine is not more than half as long as the stomach.'"

The following cut represents the form and organs of this Electrical Ray. *a* is the brain; *b*, the skin, with its glands; *c*, the eye, with its spiracle behind it; *d*, the electrical organ; *e*, branchiæ; *f*, nerves running to the pectoral fin; *g*, the spinal chord; *h*, branches of the *nervus vagus*, or eighth pair of nerves passing to the electrical organ; and *i*, the lateral nerve. In this cut, it is supposed that the front part of the dorsal skin has been removed, for the purpose of showing the electrical organs, brain, nerves, &c.

It is stated that another species of the Ray,

a native of Brazil, the *Rhinobatus electricus*, has electrical powers.

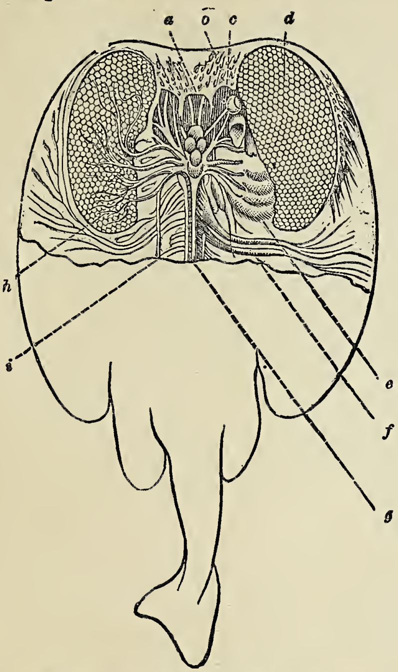


Fig. 128.—The Electrical Ray.

It will be evident, from the preceding description of the gymnotus and the torpedo, that whatever may be the actual cause of the development of free electricity in or by them, such is intimately connected with the nervous system. It has long been known, that if the eighth pair of nerves be divided, respiration and digestion cease; and an animal so treated dies of asphyxia, or suffocation. In fact, the chief functions of life in the animal are destroyed by the division of the organ. But if continuity be established by inserting a small plate each of platina or silver, and zinc, a current of electricity is not only generated, but the nervous influence is propagated; and, still further, the functions of digestion and respiration proceed as if no division of the nerve had taken place. Aldini showed that an alternation of layers of nerve and muscle, taken from an animal but recently killed, afforded evidences of an electric current, that could be appreciated by instruments employed to detect minute currents of electricity.

Hasty generalisation speedily led to the conclusion that animal vitality is the result of the development of electric currents, and their passage through the system. Experiments on dead animals, especially on a recently-executed man, dying in the full vigour of life, led to further hasty conclusions on the matter. We cannot transfer to our columns a description that may be found in Dr. Ure's *Dictionary of Chemistry*, under the head of Galvanism, of experiments that were tried on a murderer immediately after his execution, and when the blood had been drawn from the body. The results were so strikingly like those that would have been afforded by a live man in respect to gesture, expression of the face, and muscular action, that they terrified men used hourly to hospital scenes, causing some to faint, and driving others from the theatre of operation. The details, in fact, are sickening to read; but the only inference, philosophically, derivable from them is, not that electricity and vitality are identical, but that electricity is a servant or function of vitality. No sensible man would say that the cistern of his house was filled by the water-pipe that conveyed thither the fluid, or that the steam-engine, or gravitation that forced it thither, either was the cause of the sustenance of his vital energy; yet, without the pipe, the water would not have reached him; and without the force it could not have passed through the pipe. So, similarly, the nerve may, doubtless, convey the electric current, and the latter may assist in the performance of the functions of vitality; but from neither circumstance can we justly conclude that the electric force is the cause of vitality.

The sensibility to electrical influence has been already, in part, dealt with at p.198, *ante*, when we referred to the antecedent effects of the thunder-storm on individuals. But, independent of the latter, the ordinary electrical state of the atmosphere greatly affects individual constitutions. The nervous depression felt by many persons at certain seasons of the year, may be, in many cases, directly traced to the influence of an absence of free electricity. We never experimented long with the hydro-electric machine, or a large plate-glass one, when abundance of electricity was set free, without feeling a great increase in the animal spirits; and it is familiarly known to every one, that whilst, on a damp November day, lowness of spirits universally prevails, a fine frosty day or night has precisely an opposite effect. The amount of moisture in the atmosphere must, at the same time, be taken into account; but, in doing this, we must also remember that moisture is a comparatively good conductor of electricity, and, as such, may cause the abstraction of the force from the animal system. We are not prepared to enter into any discussion on such a subject, because it is impossible to gain proper premises whence to draw right conclusions. In all cases, personal observation, by individually different temperaments, is necessary; and equally so is the method of philosophical deduction and induction, only possessed by "few and far between." To attempt, therefore, to dogmatise on the effect of electricity on individuals, would not only be unwise, but useless, and lead to the most erroneous results, that would disgrace any one having the least pretension to a scientific reputation.

We conclude these elementary and introductory remarks, by describing an instrument of much value in estimating the disturbances of electrical equilibrium when such are exceedingly minute in quantity or intensity, especially in such investigations as refer to the most difficult

and uncertain part of electrical phenomena developed or evidenced in many experiments. We have already explained the law of electric induction in some of the previous pages; and, in obedience to its laws and teachings, the electrical *condenser* has been constructed. It is represented in the following cuts:—No. 1 illus-

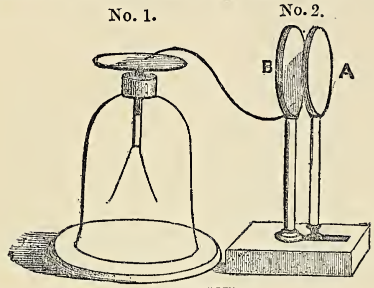
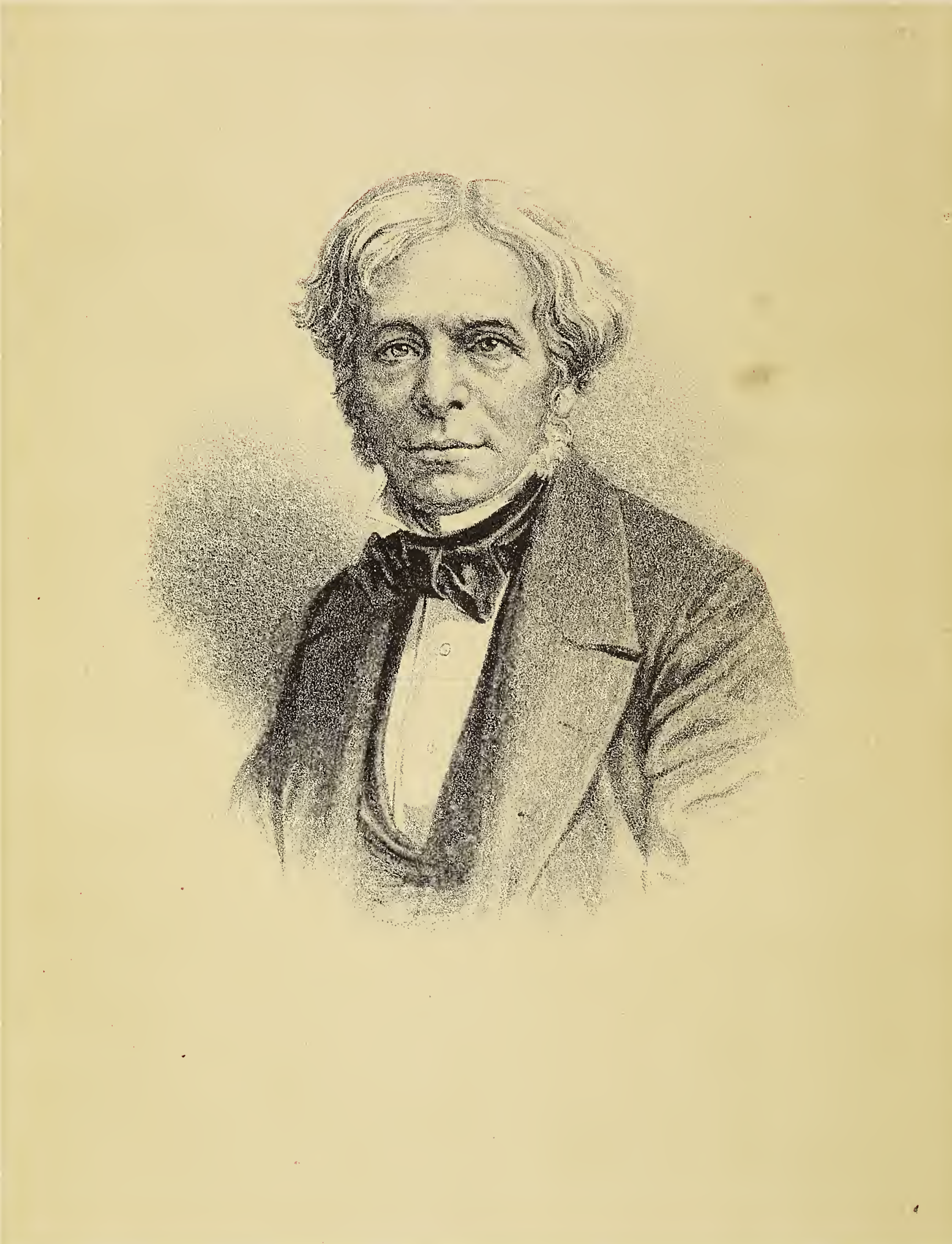


Fig. 129.

trates an ordinary gold-leaf electroscope, or electrometer, already described at p. 186, *ante*. In No. 2, B represents a metallic disc, mounted on a glass leg, and connected by a wire with No. 1. A, in No. 2, is a disc, that can either be moved on a pivot at its foot from proximity to B, or by being shifted in a slide in the frame, as shown at the foot of No. 2. By the proximity of A to B, an inductive influence is exerted, by means of which, a small charge, affecting No. 1 on the electroscope, is by induction greatly increased. Indeed, to explain the result of this condenser, we may cite the effect of a magnifying lens in respect to its action on light. By such a lens, rays of light, that otherwise would escape the eye, become collected, and produce a greatly-increased effect beyond that which would have resulted from perception by the eye alone. So, analogically, the effect of the condenser is to magnify the result of a small charge, by the inductive action of A on B. The inductive effect, however, only takes place after the charge has been communicated to B, and after A is removed: B then receives a higher or increased charge of electricity, and so the divergence of the gold leaves of the electrometer is much beyond that which would have been effected by the simple communication of the charge to them. It must be noted that the divergence of the leaves of the electroscope, as represented in the diagram, only occurs after A has been withdrawn from B; but, for convenience of illustration, that divergence is shown in the cut whilst A is near B.

We have thus endeavoured to present to our unscientific readers an outline of all the important phenomena, effects, &c., of frictional electricity; in part, of its laws and theories; and such a description of the apparatus generally employed, as will enable even the beginner to pursue the more difficult details that have yet to be investigated. We must freely admit, that, in its experimental results, so far as brilliancy and beauty are concerned, the study of frictional electricity is far behind that of the voltaic battery, the inductive coil, and other forms of electrical manifestation. In a philosophical point of view, however, all the latter depend for their investigation on that of the phenomena of frictional electricity; for they are but expansions of that department of science. It is hard to persuade those who have been unused to scientific pursuits, that there is a vast deal more real interest excited in the study of dry details, than in the repetition of brilliant and striking experiments, as shown in the lecture-room. The latter excite, like a sensational novel, our feelings of wonder and ideality. But such are only transient in their effects; whilst the careful and arduous studies of the laws of natural phenomena leave a permanent source of gratification.

Let us take, for example, any kind of astronomical phenomena—say an eclipse of the sun or moon. A considerable proportion of the inhabitants of the metropolis would give up some of the business hours of the day, or the hours of rest at night, to watch either. Yet within twenty-four hours all interest in the matter would be lost. But out of the many who would simply "look at" the eclipse, there will be an attentive few that, studiously observing all the details, will be enabled to extract from such observations facts that, confirmed by subsequent investigators, shall excite *tout le monde* in years afterwards. Another class will view, in the occurrence of the eclipse, a verification of its prediction, and, consequently, acquire a still deeper love for the study of science, because of the precision that attends its prognostications. On such, and many other grounds, therefore, we invite the careful attention and study of our readers, in regard to the discoveries that have laid the foundation of the science of electricity, and that have resulted in such wonderful benefits to mankind at large. Our preceding pages have only been a rough and unfinished picture of what electricity is, or has been. In the future we propose to trace each delineament, or line of light or shadow, and demonstrate the labours of Faraday, and his eminent contemporaries, in raising the early experiments in electricity to the extent of one of the most important branches of pure and applied science.



Michael Faraday

CHAPTER V.

EXPERIMENTAL INVESTIGATIONS OF THE LAWS OF ELECTRICAL PHENOMENA, CONDUCTION, ETC.

IN choosing the order in which to investigate the laws of electricity, much difference of opinion must be held. There is no doubt that the law of induction holds a primary place in the study of the science; indeed, it has occupied the attention of some of the leading philosophers in Europe for the last forty years, and has yet to receive a satisfactory exposition. *Conduction* is a phenomenon of electricity that is scarcely inferior to that of induction, as regards electricity; and may safely be taken as introductory to it; for it becomes a question how much conduction and induction differ.

We will take, for example, a solid conductor, such as a copper wire. No difference, at the moment, can be detected in the metal by the conduction of electricity by it, although, as we shall subsequently notice, its molecular constitution, according to our experiments, becomes greatly altered. If, however, we send through a fluid a charge of either frictional or voltaic electricity, chemical decomposition, under certain circumstances, becomes effected. Each element of a binary compound, such as water, is polarised; and from one extremity of the wire, communicating a charge, hydrogen is liberated, and, from the other, oxygen, each of these elements invariably, and under every circumstance, indicating, in its liberation, a certain affection or relation to the respective vitreous, or positive, and negative, or resinous, electricity. Here we do not propose to enter into any discussion as to the amount of effect produced; we simply speak of the effect itself.

Now, whether we send electricity through a liquid or solid conductor, we evidently affect the constitution of the body. If through a solid conductor, not continuous, but if the ends of the break of continuation be near enough, we have the phenomena of the disruptive discharge; that is, portions of the conductor at that break are affected, and light, heat, with mechanical transference, are afforded.

But whence the difference between the conducting power of bodies in relation to electricity? How is it, for example, that glass should, if dry, absolutely refuse to conduct the force; whilst a metal—say aluminium—of the same density or specific gravity, shall be an excellent conductor? On what, we ask, does the conducting power depend? Is it in the mechanical, chemical, or other affections of matter?—or is it due to some influence that we are unacquainted with?

The question is one of the utmost practical importance at the present time, when many scores of thousands of pounds, and thousands of miles of wire, are distributed in all civilised portions of the earth, to be the instrument of conveying messages from one place to another. To decide on such a question is more than has yet been possible; but we conceive that we cannot do better than first present Faraday's views of the matter, as conveyed, some years ago, in a published paper, entitled, *Electric Conduction, and the Nature of Matter.* We can afterwards enter into the discussion of the views he there propagated. The remarks are quoted *verbatim.*

Faraday commenced by taking up the doctrine of the constitution of matter, as first enunciated by Sir Isaac Newton.

"The view of the atomic constitution of matter which I think is most prevalent, is that which considers the atom as a something material, having a certain volume, upon which those powers were impressed at the creation, which have given it, from that time to the present, the capability of constituting, when many atoms are congregated together into groups, the different substances whose effects and properties we observe. These, though grouped and held together by their powers, do not touch each other, but have intervening space, otherwise pressure or cold could not make a body contract into a smaller bulk, nor heat or tension make it larger; in liquids, these atoms or particles are free to move about one another; and in vapours or gases they are also present, but removed very much further apart, though still related to each other by their powers."

He then proceeds, incidentally, to touch on the atomic theory first brought out by the celebrated Dr. Dalton, to the effect, that bodies combine in certain proportions, which he called atomic—a term now generally converted into the "equivalents" of a body. Thus, 8 pounds of oxygen combine with 1 of hydrogen to form 9 of water; 16 pounds of sulphur with 3×8, or 24 pounds of oxygen, to produce 40 of sulphuric acid; and so on. The combining proportion, in the preceding cases, being, 1 as representing hydrogen, 8 representing oxygen, and 16 as representing sulphur; such proportions being invariable in respect to their units, although being subject to multiple-combining proportions. Of this he speaks thus:—

"The atomic doctrine is greatly used one way or another in this, our day, for the interpretation of phenomena, especially those of crystallography and chemistry, and is not so carefully distinguished from the facts, but that it often appears to him who stands in the posi-

tion of student, as a statement of the facts themselves, though it is at best but an assumption, of the truth of which we can assert nothing, whatever we may say or think of its probability. The word atom, which can never be used without involving much that is purely hypothetical, is often *intended* to be used to express a simple fact; but, good as the intention is, I have not yet found a mind that did habitually separate it from its accompanying temptations; and there can be no doubt that the words definite proportions, equivalents, primes, &c., which did and do express fully all the *facts* of what is usually called the atomic theory in chemistry, were dismissed because they were not expressive enough, and did not say all that was in the mind of him who used the word atom in their stead; they did not express the hypothesis as well as the fact.

"But it is always safe and philosophic to distinguish, as much as is in our power, fact from theory. The experience of past ages is sufficient to show us the wisdom of such a course; and, considering the constant tendency of the mind to rest on an assumption—and when it answers every present purpose to forget that it is an assumption—we ought to remember that it, in such cases, becomes a prejudice, and inevitably interferes, more or less, with a clear-sighted judgment. I cannot doubt but that he who, as a mere philosopher, has most power of penetrating the secrets of nature, and guessing by hypothesis at her mode of working, will also be most careful, for his own safe progress and that of others, to distinguish that knowledge which consists of assumptions—by which I mean theory and hypothesis—from that which is the knowledge of facts and laws; never raising the former to the dignity or authority of the latter, nor confusing the latter more than is inevitable with the former.

"Light and electricity are two great and searching investigators of the molecular structure of bodies; and it was whilst considering the probable nature of conduction and insulation in bodies not decomposable by the electricity to which they were subject, and the relation of electricity to space, contemplated as void of that which by the atomists is called matter, that considerations something like those which follow were presented to my mind.

"If the view of the constitution of matter already referred to be assumed to be correct, and I may be allowed to speak of the particles of matter and of the space between them (in water, or in the vapour of water, for instance) as two different things, then space must be taken as the only continuous part, for the particles are considered as separated by space from each other. Space will permeate all masses of matter in every direction like a net, except that in place of meshes it will form cells, isolating each atom from its neighbours, and itself only being continuous."

The expressions used at the close of the preceding paragraph, refer to the general opinion, that however solid a body may be, still that its particles are separated by pores; and it has long been a matter of speculation as to what occupies these pores. Very recently, Sir William Thomson, whose labours in connection with laying the Atlantic telegraph of 1866 were so successfully, with those of his coadjutors, brought to a conclusion, has offered some speculative views on the subject. Formerly it was thought that compression of the particles of a mass resulted in forcing out light and heat; but such a material view of the cause of these forces is now rejected, motion being regarded as the primary cause in all cases of their excitement.

We next follow Faraday into his speculations as to the difference of conductors and non-conductors:—

"Then take the case of a piece of shell-lac, a non-conductor, and it would appear at once, from such a view of its atomic constitution, that space is an insulator; for if it were a conductor the shell-lac could not insulate, whatever might be the relation as to conducting power of its material atoms; the space would be like a fine metallic web, penetrating it in every direction, just as we may imagine of a heap of siliceous sand, having all its pores filled with water; or, as we may consider, of a stick of black wax, which, though it contains an infinity of particles of conducting charcoal diffused through every part of it, cannot conduct, because a non-conducting body (a resin) intervenes, and separates them one from another, like the supposed space in the lac.

"Next take the case of a metal, platinum or potassium, constituted according to the atomic theory, in the same manner. The metal is a conductor; but how can this be, except space be a conductor? for it is the only continuous part of the metal, and the atoms not only do not touch (by the theory), but, as we shall see presently, must be assumed to be a considerable way apart. Space, therefore, must be a conductor, or else the metals could not conduct, but would be in the situation of the black sealing-wax referred to a little while ago.

"But if space be a conductor, how then can shell-lac, sulphur, &c., insulate? for space permeates them in every direction. Or if space be an insulator, how can a metal, or other similar body, conduct?

"It would seem, therefore, that in accepting the ordinary atomic theory, space may be proved to be a non-conductor in non-conducting bodies, and a conductor in conducting bodies; but the reasoning ends in this—a subversion of that theory altogether: for if space be an insulator, it cannot exist in conducting bodies; and if it be a conductor it cannot exist in insulating bodies. Any ground of reasoning which tends to such conclusions as these must in itself be false."

It has long been considered that a relation subsists between the specific gravities of bodies and their equivalents, or atomic combining proportions; and this Faraday deals with, in connection with the subject of electrical conduction, in the following manner:—

"In connexion with such conclusions, we may consider shortly what are the probabilities that present themselves to the mind, if the extension

of the atomic theory which chemists have imagined, be applied in conjunction with the conducting powers of metals. If the specific gravity of the metals be divided by the atomic numbers, it gives us the number of atoms, upon the hypothesis, in equal bulks of the metals. In the following table the first column of figures expresses nearly the number of atoms in, and the second column of figures, the conducting power of, equal volumes of the metals named :—

Atoms.		Conducting Power.
1·00	gold	6·00
1·00	silver	4·66
1·12	lead	0·52
1·30	tin	1·00
2·20	platinum	1·04
2·27	zinc	1·80
2·87	copper	6·33
2·90	iron	1·00

"So here iron, which contains the greatest number of atoms in a given bulk, is the worst conductor excepting one. Gold, which contains the fewest, is nearly the best conductor; not that these conditions are in inverse proportions; for copper, which contains nearly as many atoms as iron, conducts better still than gold, and with above six times the power of iron. Lead, which contains more atoms than gold, has only about one-twelfth of its conducting power; lead, which is much heavier than tin, and much lighter than platina, has only half the conducting power of either of these metals. And all this happens amongst substances which we are bound to consider, at present, as elementary or simple. Whichever way we consider the particles of matter, and the space between them, and examine the assumed constitution of matter by this table, the results are full of perplexity.

"Now, let us take the case of potassium, a compact metallic substance, with excellent conducting powers, its oxide or hydrate a non-conductor; it will supply us with some facts having very important bearings on the assumed atomic construction of matter.

"When potassium is oxidised, an atom of it combines with an atom of oxygen to form an atom of potass, and an atom of potass combines with an atom of water, consisting of two atoms of oxygen and hydrogen, to form an atom of hydrate of potass, so that an atom of hydrate of potass contains four elementary atoms. The specific gravity of potassium is 0·865, and its atomic weight 40; the specific gravity of cast hydrate of potass, in such state of purity as I could obtain it, I found to be nearly 2, its atomic weight 57. From these, which may be taken as facts, the following strange conclusions flow. A piece of potassium contains less potassium than an equal piece of the potass formed by it and oxygen. We may cast into potassium oxygen atom for atom, and then again both oxygen and hydrogen in a twofold number of atoms, and yet, with all these additions, the matter shall become less and less, until it is not two-thirds of its original volume. If a given bulk of potassium contains 45 atoms, the same bulk of hydrate of potass contains 70 atoms nearly *of the metal potassium;* and, besides that, 210 atoms more of oxygen and hydrogen. In dealing with assumptions, I must assume a little more for the sake of making any kind of statement: let me therefore assume that, in the hydrate of potass, the atoms are all of one size, and nearly touching each other, and that in a cubic inch of that substance there are 2,800 elementary atoms of potassium, oxygen, and hydrogen; take away 2,100 atoms of oxygen and hydrogen, and the 700 atoms of potassium remaining will swell into more than a cubic inch and a-half; and if we diminish the number until only those containable in a cubic inch remain, we shall have 430, or thereabouts. So a space which can contain 2,800 atoms, and amongst them 700 of potassium itself, is found to be entirely filled by 430 atoms of potassium as they exist in the ordinary state of that metal. Surely, then, under the suppositions of the atomic theory, the atoms of potassium must be very far apart in the metal—*i. e.*, there must be much more of space than of matter in that body: yet it is an excellent conductor—and so space must be a conductor; but then what becomes of shell-lac, sulphur, and all the insulators? for space must also, by the theory, exist in them.

"Again, the volume which will contain 430 atoms of potassium, and nothing else, whilst in the state of metal, will, when that potassium is converted into nitre, contain very nearly the same number of atoms of potassium—*i. e.*, 416, and also then seven times as many, or 2,912 atoms of nitrogen and oxygen besides. In carbonate of potass, the space which will contain only the 430 atoms of potassium as metal, being entirely filled by it, will, after the conversion, contain 256 atoms more of potassium, making 686 atoms of that metal, and, in addition, 2,744 atoms of oxygen and carbon.

"These, and similar considerations, might be extended through compounds of sodium and other bodies with results equally striking; and, indeed, still more so, when the relations of one substance, as oxygen or sulphur, with different bodies are brought into comparison.

"I am not ignorant that the mind is most powerfully drawn by the phenomena of crystallisation, chemistry, and physics generally, to the acknowledgment of centres of force. I feel myself constrained, for the present, hypothetically, to admit them, and cannot do without them; but I feel great difficulty in the conception of atoms of matter which, in solids, fluids, and vapours, are supposed to be more or less apart from each other, with intervening space not occupied by atoms, and perceive great contradictions in the conclusions which flow from such a view.

"If we must assume at all, as, indeed, in a branch of knowledge like the present we can hardly help it, then the safest course appears to be to assume as little as possible, and, in that respect, the atoms of Boscovich appear to me to have a great advantage over the more usual notion. His atoms, if I understand aright, are mere centres of forces or powers, not particles of

matter, in which the powers themselves reside. If, in the ordinary view of atoms, we call the particles of matter away from the powers, *a*, and the system of powers or forces in and around it, *m*, then, in Boscovich's theory, *a* disappears, or is a mere mathematical point; whilst, in the usual notion, it is a little, unchangeable, impenetrable piece of matter, and *m* is an atmosphere of force grouped around it.

"In many of the hypothetical uses made of atoms, as in crystallography, chemistry, magnetism, &c., this difference in the assumption makes little or no alteration in the results; but in other cases, as of electric conduction, the nature of light, the manner in which bodies combine to produce compounds, the effects of forces, as heat or electricity on matter, the differences will be very great.

"Thus, referring back to potassium—in which, as a metal, the atoms must, as we have seen, be, according to the usual view, very far apart from each other—how can we for a moment imagine that its conducting property belongs to it, any otherwise than as a consequence of the properties of the space, or, as I have called it above, the *m?* So also its other properties, in regard to light or magnetism, or solidity, or hardness, or specific gravity, must belong to it, in consequence of the properties or forces of the *m*, not those of the *a*, which, without the forces, is conceived of as having no powers. But then surely the *m* is the *matter* of the potassium; for where is there the least ground (except in a gratuitous assumption) for imagining a difference, in kind, between the nature of that space, midway between the centres of two contiguous atoms, and any other spot between these centres?—a difference in degree, or even in the nature of the power consistent with the law of continuity, I can admit, but the difference between a supposed little hard particle, and the powers around it, I cannot imagine.

"To my mind, therefore, the *a*, or nucleus, vanishes, and the substance consists of the powers, or *m;* and, indeed, what notion can we form of the nucleus, independent of its powers? All our perception and knowledge of the atom, and even our fancy, is limited to ideas of its powers: what thought remains on which to hang the imagination of an *a*, independent of the acknowledged forces? A mind just entering on the subject may consider it difficult to think of the powers of matter independent of a separate something to be called *the matter;* but it is certainly far more difficult, and, indeed, impossible, to think of, or imagine, that *matter* independent of the powers. Now, the powers we know and recognise in every phenomena of the creation, the abstract matter in none; why then assume the existence of that of which we are ignorant, which we cannot conceive, and for which there is no philosophical necessity?

"Before concluding these speculations, I will refer to a few of the important differences between the assumption of atoms consisting merely of centres of force, like those of Boscovich, and that other assumption of molecules of something specially material, having powers attached in and around them.

"With the latter atoms, a mass of matter consists of atoms and intervening space; with the former atoms, matter is everywhere present, and there is no intervening space unoccupied by it. In gases, the atoms touch each other just as truly as in solids. In this respect the atoms of water touch each other, whether that substance be in the form of ice, water, or steam; no mere intervening space is present. Doubtless the centres of force vary in their distance one from another; but that which is truly the matter of one atom touches the matter of its neighbours.

"Hence matter will be *continuous* throughout; and, in considering a mass of it, we have not to suppose a distinction between its atoms and any intervening space. The powers around the centres give these centres the properties of atoms of matter; and these powers, again, when many centres, by their conjoint forces, are grouped into a mass, give to every part of that mass the properties of matter. In such a view all the contradiction resulting from the consideration of electric insulation and conduction disappears.

"The atoms may be conceived of as highly *elastic*, instead of being supposed excessively hard and unalterable in form; the mere compression of a bladder of air between the hands can alter their size a little; and the experiments of Cagniard de la Tour carry on this change in size, until the difference in bulk, at one time and another, may be made several hundred times. Such is also the case when a solid or a fluid body is converted into vapour.

"With regard, also, to the *shape* of the atoms, and, according to the ordinary assumption, its definite and unalterable character, another view must now be taken of it. An atom, by itself, might be conceived of as spherical or spheroidal, or, where many were touching in all directions, the form might be thought of as a dodecahedron, for any one would be surrounded by, and bear against, twelve others on different sides. But if an atom be conceived to be a centre of power, that which is ordinarily referred to under the term *shape*, would now be referred to the disposition and relative intensity of the forces. The power arranged in and around a centre might be uniform, in arrangement and intensity, in every direction outwards from that centre, and then a section of equal intensity of force, through the radii, would be a sphere; or the law of decrease of force, from the centre outwards, might vary in different directions, and then the section of equal intensity might be an oblate or oblong spheroid, or have other forms; or the forces might be disposed so as to make the atom polar; or they might circulate around it equatorially, or otherwise, after the manner of imagined magnetic atoms. In fact, nothing can be supposed of the disposition of forces in or about a solid nucleus of matter, which cannot be equally conceived with respect to a centre.

"In the view of matter now sustained as the lesser assumption, matter, and the atoms of matter, would be mutually penetrable. As regards the mutual penetrability of matter, one would think that the facts respecting potassium and its compounds, already described, would be enough to prove that point to a mind which accepts a fact for a fact, and is not obstructed in its judgment by preconceived notions. With respect to the mutual penetrability of the atoms, it seems to me to present, in many points of view, a more beautiful, yet equally probable and philosophical, idea of the constitution of bodies than the other hypotheses, especially in the case of chemical combination. If we suppose an atom of oxygen, and an atom of potassium, about to combine and produce potass, the hypothesis of solid, unchangeable, impenetrable atoms places these two particles side by side, in a position easily, because mechanically, imagined, and not unfrequently represented; but if these two atoms be centres of power, they will mutually penetrate to the very centres, thus forming one atom or molecule, with powers of the two constituent atoms; and the manner in which two or many centres of force may in this way combine, and afterwards, under the dominion of stronger forces, separate again, may, in some degree, be illustrated by the beautiful case of the conjunction of two sea waves of different velocities into one; their perfect union for a time, and final separation into the constituent waves—considered, I think, at the meeting of the British Association at Liverpool. It does not, of course, follow from this view that the centres shall always coincide; for that will depend upon the relative disposition of the powers of each atom.

"The view now stated of the constitution of matter would seem necessarily to involve the conclusion that matter fills all space, or, at least, all space to which gravitation extends, including the sun and its system; for gravitation is a property of matter dependent on a certain force, and it is this force that constitutes the matter. In that view, matter is not merely mutually penetrable, but each atom extends, so to say, throughout the whole of the solar system, yet always retaining its own centre of force. This, at first sight, seems to fall in very harmoniously with Mosotti's mathematical investigations, and reference of the phenomena of electricity, cohesion, gravitation, &c., to one force in matter; and again, also, with the old adage, 'Matter cannot act where it is not.' But it is no part of my intention to enter into such considerations as these, or what the bearings of this hypothesis would be on the theory of light, and the supposed ether. My desire is rather to bring certain facts, from electrical conduction and chemical combination, to bear strongly upon our views regarding the nature of atoms and matter, and so to assist in distinguishing, in natural philosophy, our real knowledge; *i.e.*, the knowledge of facts and laws from that which, though it has the form of knowledge, may, from its including so much mere assumption, be the very reverse."

The preceding speculations are of great interest, in a philosophical point of view, and need no commendation, on our part, to scientific persons as worthy of careful study. At first sight, a large proportion of the quotation—or rather what is a copy of a letter, written by Faraday, dated Royal Institution, January 25th, 1844, and addressed to Mr. Richard Taylor—seems, for the present, barely relevant to the subject. But Faraday, as will be subsequently shown, bases all his theories on an affection of the "contiguity of the particles of matter;" and we shall see that his theories of conduction, insulation, and induction, are such as to unite, in an extremely simplified form, those phenomena which are, at first sight, apparently heterogeneous.

The size of the conductor influences the amount of its conducting power. This circumstance has been already frequently alluded to in the preceding pages; as, for example, at p. 198, *ante*, the effects on too small a conductor were illustrated by the destruction of the gold foil, or wires; the latter being too small to carry off the charge: whereas, at p. 209, *ante*, an instance was recorded in which even the flash of lightning pursued its way through a bell-wire without injuring a man sleeping in a bed adjacent to it. The quantity of frictional electricity that can be set free by the most powerful of our artificial instruments, is too small to require any great thickness of metal; copper wire, of No. 16 gauge, being amply sufficient for that purpose. With a powerful voltaic battery, however, such a wire might be melted in a length of several feet; hence our readers will perceive the truth of Faraday's statement, given at p. 205, *ante*, that a wire each of zinc and platina, not an inch long, will afford as much electricity, in *quantity*, as the most powerful flash of lightning; for, whilst a few plates of zinc and platina, properly arranged in a voltaic battery, are sufficient to cause the fusion of several feet of copper bell-wire (as we have just seen), even a flash of lightning is incapable of producing that result.

So great is the tension or intensity to overcome obstacles on conductors of free frictional electricity, that it is scarcely possible to call any liquid, at ordinary temperatures, absolutely non-conducting or insulating: in fact, as shown at p. 193, Fig. 114, *ante*, even a vacuum permits of the passage of the fluid. The resisting, or non-conducting power of glass, shell-lac, &c., remarked on by Faraday at p. 214, *ante*, becomes, therefore, very singular and anomalous.

Length of the conductor is an essential element in respect to its conducting power; for, at least as regards voltaic electricity, the greater the length of the conductor, the more is the progress of the current retarded, and even entirely stopped. With the voltaic battery, the resistance to the passage or conduction of the current, is overcome by increasing the number of cells employed—each additional one adding to the intensity of the battery, and its power of overcoming the resistance of the conductor. Not so, at least so far as any length that has

yet been tried, does this influence materially affect the passage of free frictional electricity. Its tension, or power to overcome such an obstacle, is too great, provided, as we have already remarked, the conductor has sufficient means to carry the charge without undergoing mechanical disruption or combustion.

We therefore observe, that all the calorific, luminous, and most other effects, described at pp. 193 to 205 result from the objects tried having too little power to carry the charge conveyed by or through them. Consequently, by deficient power of conduction, the phenomena alluded to are produced.

The production of one force by the resistance to the passage of another, is a remarkable feature in experimental philosophy. It was formerly merely noticed, but not deeply studied. We cannot remember a passage in the whole of Newton's *Principia* that distinctly alludes to it. In fact, a much larger accumulation of facts was required than he possessed, to bring the intellect of man to the eduction of any results. Independently of this, for a century after Newton's day—that is, till towards the end of the eighteenth century—no instruments of sufficient force to produce either frictional or current electricity, to any extent, had been constructed.

In 1833, Faraday published the results of some experiments on conduction generally, but especially in regard to the effect of ice on the passage of both frictional and voltaic electricity. He found that the thinnest film of ice was sufficient to prevent the passage of a voltaic current from a powerful battery between its two poles, although, when the ice was liquefied, the current, of course, readily passed. He remarks, however (§ 392)—"This insulating power of ice is not effective with electricity of exalted intensity. On touching a diverged gold-leaf electrometer (see *ante*, p. 186, Fig. 101) with a wire connected with the platina, whilst the tin case was touched by the hand, or another wire, the electrometer was instantly discharged."*

The tin case, and general arrangement above alluded to, as used in these and other experiments we shall describe, as made by him, were as follows (§ 383):—"Tin vessels were formed five inches deep, one inch and a quarter wide in one direction, of different widths from three-eighths to five-eighths of an inch in the other, and open at one extremity. Into these were fixed, by corks, plates of platina, so that the latter should not touch the tin cases; and copper wires having been previously soldered to the plate, these were easily connected, when required, with a voltaic pile. Then distilled water, previously boiled for three hours, was poured into the vessels, and frozen by a mixture of salt and snow, so that pure, transparent, solid ice, intervened between the platina and the tin."

Faraday, with his usual persistence to discover every phase of a phenomenon, and with his usual sagacity, determined to try whether this "*law of the assumption of conducting power during liquefaction, and loss of it during congelation*, would be peculiar to water;" and he proceeded to ascertain its influence in other cases. He found, that whilst chloride of lead was kept in a fused condition, it conducted the current of a voltaic battery very readily; but the instant that it was allowed to solidify, the passage of the current was stopped, although the platina terminals of the conducting wires were not more than the sixteenth of an inch apart. He tried the experiment on many other substances, with the same result.

But a remarkable fact was also proved in relation to many bodies that are non-conductive or insulative when cold. Faraday found (§ 405)—"The following are bodies which acquired no conducting power upon assuming the liquid state—viz., sulphur, phosphorus; iodide of sulphur, periodide of tin; orpiment, realgar; glacial acetic acid, mixed margaric and oleic acids, artificial camphor, naphthaline, resin, gum, sandarach, shell-lac."

When the charge of a plate machine, fifty inches in diameter, fitted with double rubbers, was sent through a piece of ice in the tin case, as before described, it was found that ice actually conducted, although the effect was trifling. The passage of the electricity of the machine only sufficed to open the leaves of the electrometer two inches; whilst, in another experiment, a thickness of one-eighth of an inch of ice so obstructed the passage of the electricity, that the leaves of the electrometer opened only half an inch.

Faraday sums up his views on conduction (Series iv., § 443) thus:—

"I venture to give the following summary of the conditions of electric conduction in bodies; not, however, without fearing that I may have omitted some important points.

"All bodies conduct electricity in the same manner, from metals to lac and gases, but in very different degrees [see our remarks on conductors and non-conductors, at p. 176, *ante*].

"Conducting power is, in some bodies, powerfully increased by heat, and, in others, diminished, yet without our perceiving any accompanying essential electrical difference, either in the bodies or in the changes occasioned by the electricity conducted.

"A numerous class of bodies, insulating electricity of low intensity, when solid, conduct it freely when fluid; and are then decomposed by it. [This remark almost exclusively refers to the passage of the current of a voltaic battery through them.] But there are many fluid bodies which do not sensibly conduct electricity of this low intensity; there are some which conduct it, and are not decomposed; nor is fluidity essential to decomposition." This remark also chiefly applies to the passage of the voltaic current; and the remainder of the laws enunciated in this section may be here omitted, because they only refer to the conduction of electricity of low intensity, as that of the voltaic current.

In Series xii., § 1,320, Faraday remarks, in extension and explication of the views already

* Series iv., *Experimental Researches in Electricity.*

quoted—"Though assumed to be essentially different, yet neither Cavendish nor Poisson attempt to explain by, or even state in their theories, what the essential difference between insulation and conduction is. Nor have I anything, perhaps, to offer in this respect, *except* that, according to my view of induction, insulation and conduction depend upon the same molecular action of the dielectrics* concerned; are only extreme degrees of *one common condition* and effect; and in any sufficient mathematical theory of electricity, must be taken as cases of the same kind. Hence the importance of the endeavour to show connection between them under my theory of the electrical relations of contiguous particles." This theory will be described when we enter on the investigation of the phenomena of induction.

Faraday thus expresses his opinion that insulators and conductors are bodies of one class. He is more definite, however, in Series xiv. He there says, that when particles of matter, whether of insulating or conducting matter, are subject to inductive phenomena, they are, as wholes, conductors. In § 1,675, he observes—

"That the *ready* communication of forces between contiguous particles constitutes conduction, and the *difficult* communication, *insulation;* conductors and insulators being bodies whose particles naturally possess the property of communicating their respective forces easily or with difficulty; having their differences just as they have differences of any other natural property."—In a letter addressed to Dr. Hare, of Pennsylvania, in 1840, Faraday refers to the remarks we have just quoted as still being those he maintained. But he becomes illustrative in that reply. He says, after citing many theories that had been formerly prevalent, as the maintaining opposite principles, such as heat and cold, levity and weight (all of which are discarded)—"I think it, therefore, important that we try to ascertain whether insulation and conduction are cases of the same class, just as it is important to know that hot and cold are phenomena of the same kind. As it is of consequence to show that smoke ascends, and that a stone descends, in obedience to one property of matter; so I think it is of consequence to show that one body insulates and another conducts, only in consequence of a difference of degree in one common property which they both possess; and that, in both cases, the effects are consistent with my theory of induction."

The preceding quotation from Faraday's views, as expressed in his *Experimental Researches*, thus reduces all bodies to be conductors, differing only in degree; and that insulation and conduction fall under an analogous category. *Vivâ voce*, we have repeatedly heard him express the same view, both privately and at the lecture-table; for he was not one to arrive at any conclusion or theory without having tried every method of experiment to afford him sound data, whence he could safely draw such conclusions. When we enter into the question of induction, the subject will be still further illustrated; and we shall find a proof of the truth of his view, that "electric induction is an action of the contiguous particles of the insulating medium, or dielectric;" and, still further, have the phenomena of conduction, insulation, and induction placed in their proper relation to each other, and the phenomena of static electricity.—We have thus endeavoured to lay before our readers some of the most important laws that govern the conduction of free electricity produced by friction, or its analogues. The subject has many difficulties, because of its uncertainties. Still Faraday did much to simplify it, and was the first to present such a theory, embracing many cases, as satisfactorily accounts for a large variety of phenomena.

When we treat on voltaic electricity, the subject will be more largely dealt with; for it is one of the greatest consequence in the theory and applications of current force, and its phenomena.

CHAPTER VI.

EXPERIMENTAL INVESTIGATIONS OF THE LAWS OF ELECTRICAL PHENOMENA; INDUCTION.

The phenomena of electric induction have already had frequent notice in the preceding pages; but prominently when the principles of the Leyden jar were explained. We also gave, at p. 178 *ante*, a popular illustration of what electrical induction is; what are its effects; and so forth. It is now necessary that we should enter into a closer investigation of the subject, more particularly in reference to the invaluable discoveries of Faraday. Although primarily, and chiefly, dealing here with induction relating to friction or tension electricity, we shall have also, occasionally, to import into our remarks questions affecting the induction as resulting from electricity excited by chemical action.

The term *dielectric*, constantly used by Faraday, has been already explained as referring to an insulating material capable of induction, or becoming in that condition which is indicative of induction or inductive effects. Thus, a thin plate of glass, shell-lac, and many other substances having either a vitreous or resinous nature, are dielectrics. Many circumstances,

* Substances such as glass, which, as in the Leyden jar, allow of induction being effected on their surface; the glass of the jar being a dielectric.

however, interfere with their efficiency in that respect. For example, if the glass of the Leyden jar (see *ante*, p. 189) be thick, it would be impossible to charge it, because induction, under such circumstances, could not take place. In the preceding chapter, we showed that, as proved by Faraday, conduction, insulation, and induction, are all mutually related. In fact, we may look on glass as an exceedingly bad conductor, but capable of polarisation when subject to the inductive influence of the electric charge as communicated by the prime conductor of the electrical machine, or by any other means, as the electrophorus (see p. 182), &c. Now the greater the thickness of a sheet of glass undergoing the process of induction, the less does the conducting power of its contiguous particles become. Therefore, in choosing a Leyden jar, as already pointed out, the homogeneity of its structure is not only essential, but it is equally so that it shall be sufficiently thin, at the same time not too much so, lest an overcharge should destroy it (see *ante*, p. 189). In this lies the difficulty of getting a number of jars to work equally. One will get overcharged, whilst another has barely become half charged. In a large Leyden battery, and with a powerful machine in good action, the chances are that the thin jar will crack, by the occurrence of spontaneous discharge, before the rest of the jars become properly charged. These observations may be perused together with those already given at p. 188, *ante*, where the construction, management, &c., of the Leyden battery were detailed. In repeating any of the experiments that are about to be described, it will be necessary that all the precautions already mentioned at p. 180, *ante*, should be carefully attended to.

It may assist many of our readers, if, before entering into the proposed investigation, we point out the analogies of magnetic induction to electric induction. If a piece of good-tempered steel be rubbed, by means of a bar magnet, at each end, respectively, by the opposite poles of the magnet—that is, one end of the steel with the north pole, and the other with the south pole of the magnet—a condition of magnetism will be induced in the steel, by which it will acquire the directive, or polar, and the attractive powers of the original magnet: that is, if the rubbed piece of steel be suspended horizontally, its polarity will be evinced by its point west of north and east of south; whilst its attractive power will be evidenced by placing it near some iron filings, which it will attract.

It is not even necessary to rub the piece of steel; for if it be only placed in contact with a bar magnet, of the same length as itself, it will have *induced* in it these magnetic conditions.

Still further, if this magnetised piece of steel be rubbed against another, but unmagnetised, piece, it will communicate to the latter its properties; and this last can similarly induce magnetism in another unmagnetised piece. In fact, it is by this process that any number of magnets may be made from one, provided all circumstances requisite to produce the full effect be attended to.

Now it is precisely in this way that electric induction takes place. The moment a body becomes excited by electricity, it affects all others adjacent to it, rendering their poles, to a certain degree, analogous to the state of polarity described as possessed by the bar magnet, and also communicating an attractive and repulsive power, equally analogous to that exhibited by any form of the artificial or natural magnet.

We now turn to the early experiments and conclusions of Faraday; first observing that, even in his later days, he found no reason to in any way modify the conclusion which he had arrived at.

His eleventh series of *Experimental Researches*, published in 1837, is introduced by remarks on induction, and action of contiguous particles. In respect to the use of the word *contiguous*, he explains—"The word contiguous is, perhaps, not the best that has been used here and elsewhere; for, as particles do not touch each other, it is not strictly correct [see *ante*, p. 214]. I was induced to employ it, because, in its common acceptation, it enabled me to state the theory plainly, and with facility. By contiguous particles I mean those which are next" [to each other].

In introducing the subject, Faraday remarks (§ 1,162)—"Amongst the actions of different kinds into which electricity has been conventionally sub-divided, there is, I think, none which excels, or even equals in importance, that of *induction*. It is of the most general influence in electrical phenomena, appearing to be concerned in every one of them, and has, in reality, the character of a first, essential, and fundamental principle. Its comprehensiveness is so important, that I think we cannot proceed much further in the investigation of the laws of electricity without a more thorough understanding of its nature; how otherwise can we hope to comprehend the harmony and even unity of action, which, doubtless, governs electrical excitement by friction, by chemical means, by heat, by magnetic influence, by evaporation, and even by the living being?"

Faraday was a strong believer in the theory of Du Fay, already explained at p. 209, *ante*, as that which supposes the existence of two kinds of electricity, in contradistinction to the single theory of Franklin. In fact, the whole of Faraday's researches, results, discoveries, and theories are based on the double theory. In § 1,163, he observes—"In the long-continued course of experimental inquiry in which I have been engaged, this general result has pressed on me constantly—namely, the necessity of admitting two forces, or two forms or directions of a force, combined with the impossibility of separating these two forces (electricities) from each other, either in the phenomena of statical electricity [the force as excited by friction, &c.], or those of the current [as in the voltaic battery]. In association with this, the impossibility, under any circumstances as yet, of absolutely charging matter of any kind with one or the other electricity only, dwelt on my mind, and made me wish and search for a clearer view than any that

I was acquainted with, of the way in which electrical powers and the particles of matter are related; especially in inductive actions, upon which almost all others appear to rest."

It will be impossible for us here to enter into all the train of experimental investigation that led Faraday to certain conclusions, hereafter to be detailed; for, in his experiments, he constantly associated the chemical, decomposing, or electrolytic action of the voltaic current with the inductive effects of static electricity, supporting and illustrating the one by the other.* Independently of this, he had to go through a kind of maze of uncertainty, mentally and experimentally, that he cleared up, and that, to lead our readers through, would be stale and unprofitable. For the present we shall, therefore, adduce the general results at which he arrived, as expressed by him in § 1,295, *et seq.*, in Series xi. They are as follow:—

"Thus *induction* appears to be essentially an action of contiguous particles, through the intermediation of which, the electric force originating or appearing at a certain place, is propagated to, or sustained at, a distance, appearing there as a force of the same kind, exactly equal in amount, but opposite in its direction and tendencies. Induction requires no sensible thickness in the conductors, which may be used to limit its extent: an uninsulated leaf of gold may be made very highly positive on one surface, and as highly negative on the other, without the least interference of the two states whilst the inductions continue. Nor is it affected by the nature of the limiting conductors, provided time be allowed, in the case of those that conduct slowly, for them to assume their final state."

Here we must notice that it is only on the *surface* that electrical action exists in charging. Coulomb was the first to point out this fact; and it has given rise to a kind of popular term, called the *outsidedness* of electricity. The following illustration and remarks will explain what is here meant.

That the surface alone is affected by static electricity, may be experimentally illustrated by the apparatus figured in the following cut.

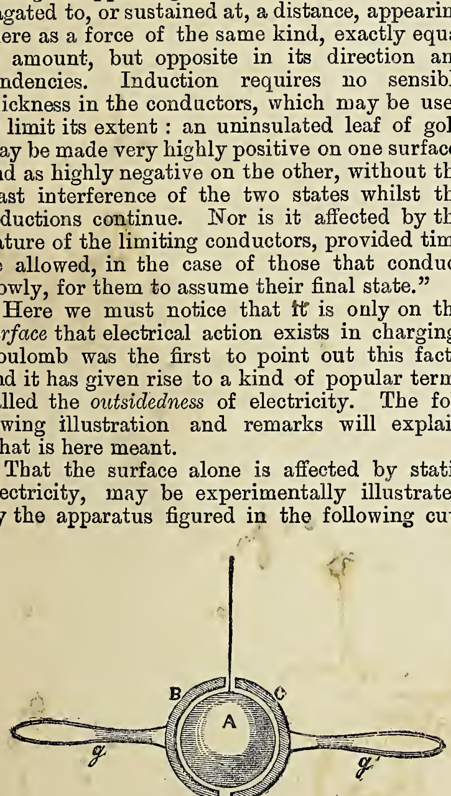


Fig. 130.

A is a brass ball, insulated by suspending it on a silk thread. B and C are two metallic cups, capable of encircling A; and each fitted with glass handles, *g g'*. The ball A is charged in the usual manner. If it be then enclosed within the metal hemispheres, as shown in the preceding engraving, the latter, on removal, will have acquired all the charge previously on the ball.

We shall, however, hereafter show that dielectrics are, to a certain extent, permeated by an electric charge, which will therefore, in part, remain on their surface, producing the phenomenon of the *residual charge*—to be hereafter noticed, with the explanation that Faraday gives of its cause.

The following remarks, by an able writer, further illustrate this part of our subject:—"Starting from the original proposition—that electricity is alone confined to the outside of bodies—it will now be desirable to trace its relation to conductors of various shapes: and here I shall have occasion to employ a term already adopted—*outsidedness*. A slight consideration of various mathematical solids, will demonstrate that each solid possesses an amount of outsidedness peculiar to itself; understanding, by that term, the mutual distance of points on the surface of each solid from the latter's centre. It will be evident that a sphere will have this outsidedness more equally diffused than any other form whatever; and that a point will depart to the farthest extent possible from this condition. It follows, therefore, that electricity should be most equably diffused over the surface of a sphere; and in proportion as the conductor assumes the pointed form, so will the electric inequality be greatest. Experiment bears out the supposition most remarkably. If a spherical insulated conductor be brought into communication with the machine, and sparks drawn from the sphere by approaching it with a metallic knob, it will be found that, on all aspects of the spherical conductor, sparks of equal size—in other words, of equal character or power—may be drawn. Immediately, however, that the spherical form is departed from, a different result is obtained. Taking a cylinder, for instance, it will be found that a spark drawn from either extremity differs in quality from the spark drawn from either side; and, in short, without needlessly multiplying further examples, a similar progression of results will be made evident as the experimenter proceeds from the spherical to the pointed type. At length, when arrived at the pointed form, the experimenter will discover that the electrical condensation tension—or, to adopt the language of theory, electrical pressure—is so great, that no spark whatever can be drawn from the point from which the electricity escapes in a continuous stream. To demonstrate this proposition, nothing more is required than the attachment of a needle to a prime conductor in such a manner that the point of the needle looks outward. Under this arrangement it will be impossible to retain electricity on the prime conductor; and if the experiment be performed in a darkened room, the escape of electricity will be rendered manifest by the appearance of a luminous object, known as the electric pencil or brush.

"The preceding experiment has been described, for the sake of simplicity, as though the passage of electricity had reference to the prime

* See subsequent chapters on Voltaic Electricity, Electro-Chemistry, &c.

conductor of the machine alone, considered as an electric source; but it will be obvious, from a proper application of the theory of induction already explained, that the machine prime conductor can only be regarded as the representative of one member of a duality, the second member of which is the whole earth. In other words, regarding the prime conductor of an electrical machine as electrified + or positive, this electricity must be balanced by its counterpart of — or negative electricity existing on some other body; which body, provided no amount of insulation take place, is the whole earth. Whence it follows, that all which has been stated in reference to the giving out of electricity by the prime conductor, or conductors, of various shapes, brought into electric communication with it, applies conversely to a reversal of the arrangements already detailed; or, to be practical, if a needle attached to the machine prime conductor be potent in giving out electricity to the earth prime conductor, so, conversely, a needle attached to the earth prime conductor (*i.e.*, held in the operator's hand) will be equally potent in receiving electricity from the prime conductor from the machine; and, generally, the proposition, in its widest significance, may be thus embodied—*The capability of any mechanical form for giving electricity, is equal to its capability for receiving it.*"

Continuing the summary of results, as obtained by Faraday, in regard to induction, he remarks, in § 1,296—

"But with regard to the dielectrics, or insulating media, matters are very different." Presuming induction to have some particular relation to the different kinds of matter through which it would be excited, or a specific electric induction for different bodies to exist, proving the dependence of induction on the particles, Faraday goes on to say—"Their thickness [that is, of the dielectrics] has an immediate and important influence on the degree of induction [see our remarks on this subject in relation to Leyden jars, at p. 189, *ante*]. As to their quality, although all gases and vapours are alike, whatever their state, there are differences which prove the existence of specific inductive capacities—these differences being, in some cases, very great.

"The direct inductive force, which may be conceived to be excited in lines between the two limiting and charged conducting surfaces, is accompanied by a lateral or transverse force, equivalent to a dilatation or repulsion of these representative lines; or the attractive force which exists amongst the particles of the dielectric, in the direction of the induction, is accompanied by a repulsive or a diverging force in the transverse direction.

"Induction appears to consist in a certain polarised state of the particles, into which they are thrown by the electrified body sustaining the action, the particles assuming positive and negative points or parts, which are symmetrically arranged with respect to each other and the inducting surfaces or particles. The state must be a forced one, for it is originated and sustained only by force, and sinks to the normal or quiescent state when that force is removed. It can be continued only in insulators by the same portion of electricity, because they can only retain this state of the particles.

"The principle of induction is of the utmost generality in electric action. It constitutes *charge* in every ordinary case, and probably in every case; it appears to be the cause of all excitement, and to precede every current. The degree to which the particles are affected in this their forced state, before discharge of one kind or another supervenes, appears to constitute what we call *intensity.*

"When a Leyden jar is *charged*, the particles of the glass are forced into this polarised and constrained condition by the electricity of the charging apparatus. *Discharge* is the return of these particles to their natural state from their state of tension, whenever the two electric forces are allowed to be disposed of in some other direction.

"All charge of conductors is on their surface; because, being essentially inductive, it is there only that the medium capable of sustaining the necessary inductive state begins. If the conductors are hollow, and contain air, or any other dielectric, still no charge can appear upon that internal surface, because the dielectric there cannot assume the polarised state throughout, in consequence of the opposing actions in different directions."

We may here break off for a few moments, in detailing Faraday's views of induction, to make some remarks on what is called the *residual charge* of the Leyden jar or battery. In the preceding paragraph but one, the legitimate conclusion of those not acquainted with electricity would be, that the moment the Leyden jar or battery is discharged, the union of the electricities is completely effected, and the polarisation of the particles of the dielectric has ended. But such is not always the case, as we have stated at a previous page. If the jar, after being *apparently* quite discharged, be approached in the usual manner by the discharger, a spark will again pass. In exceedingly dry weather, during the winter of 1855-'6, requesting an assistant to lift down a jar that had been used with the hydro-electric machine (see p. 185, *ante*) on the previous evening, although sixteen hours had elapsed, the jar had sufficient charge to give him so powerful a shock as to cause him to let it fall and break it, he having touched the knob and the exterior simultaneously. This occurred so frequently during the dry weather, that a rule was made amongst the assistants never to touch a jar on the next day after use until it had been tried by the discharger. We may add that the jars were kept in excellent order, free from dust, &c.; and that a long period of dry weather, with an east wind, had prevailed.

On such phenomena Faraday (§ 1,247-8) remarks—

"It would appear that the best solid insulators—such as shell-lac, glass, and sulphur—have conductive properties to such an extent

that electricity can penetrate them bodily, though always subject to the overruling condition of induction. As to the depth to which the forces penetrate in this form of charge of the particles, theoretically, it should be throughout the mass; for what the charge of the metal does for the portion of dielectric next to it [as in the Leyden jar], should be done by the charged dielectric for the portion next beyond it again; but, probably, in the best insulators the sensible charge is to a very small depth only in the dielectric, for otherwise more would disappear in the first instance, whilst the original charge is sustained; less time would be required for the assumption of the particular state; and more electricity would reappear as return charge.

"The condition of time required for the penetration of the charge is important, both as respects the general relation of the case to conduction, and also the removal of an objection that might otherwise properly be raised to certain results respecting specific inductive capacities.

"It is the assumption for a time of this charged state of the glass between the coatings in the Leyden jar, which gives origin to a well-known phenomenon, usually referred to the diffusion of electricity over the uncoated portion of the glass—namely, the *residual charge.* The extent of charge which can spontaneously be recovered by a large battery, after perfect uninsulation of both surfaces, is very considerable; and by far the largest portion of this is due to the return of electricity in the manner described. A plate of shell-lac, six inches square and half an inch thick, or a similar plate of spermaceti, an inch thick, being coated on opposite sides with tin-foil, as in a Leyden arrangement, will show this effect exceedingly well."

The preceding quotations from the views of Faraday, in relation to static induction, place the reader in possession of a summary of the most important of its proved and received laws; but there are many matters of detail to explain respecting the phenomena of induction. The form and distance of bodies under induction, and conductors, are matters of importance. Thus "an electrified cylinder is more affected by the influence of the surrounding conditions (which complete the condition of charge) at the ends than the middle; and a point is brought into a higher condition than a ball; because, by relation to the conductors around, more inductive force terminates on its surface than on an equal surface of the ball with which it is compared." On this subject we have made remarks at p. 221, *ante*, where the result is also illustrated by a cut, showing how a small ball is preferred, as a channel of conduction or induction, under certain circumstances.

In respect to the terms *lines of inductive force*, and *curved lines of force* (§ 1,304), Faraday makes the following remarks. He used "the phrases *lines of inductive force*, and *curved lines of force*, in a general sense only—just as we speak of the lines of magnetic force. The lines are imaginary, and the force in any part of them is, of course, the resultant of compound forces, every molecule being related to every other molecule, in all directions, by the tension and reaction of those which are contiguous. The transverse force is merely this relation considered in a direction oblique to the lines of inductive force." In respect to *polarity*, or the *polar state*, he remarks, that such "state may be considered, in common induction, as a forced state, the particles tending to return to their normal condition. It may probably be raised to a very high degree by approximation of the inductric (charged) and inducteous (assuming an opposite electrical state by induction) bodies, and by other circumstances." The phenomena of polarity is especially manifested during the action of the voltaic current in electrolysation, or chemical decomposition effected by the current (§ 1,686, Series xiv.)

In a letter to R. Phillips, Esq., F.R.S., dated February, 1843, Faraday suggested some simple, but conclusive, experiments on some phases of electric induction. He remarks—"Their value consists in their power to give a very precise and decided idea to the mind respecting certain principles of inductive electric action. * * * They are the expression and proof of certain parts of my view of induction" (see *ante*, p. 221). The experiment and his remarks are as follow:—

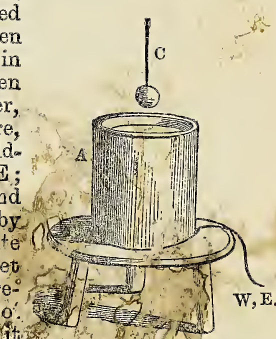


Fig. 131.—E represents an Electrometer, such as is shown at p. 184, *ante.*

"Let A, in the diagram, represent an insulated pewter ice-pail, ten and a-half inches in height, and seven inches in diameter, connected by a wire, W, with a delicate gold-leaf electrometer, E; and let C be a round brass ball, insulated by a dry thread of white silk, three or four feet in length, so as to remove the influence of the hand holding it from the pail below. Let A be perfectly discharged; then let C be charged at a distance by a machine or Leyden jar, and introduced into A, as in the figure. If C be positive, E will also diverge positively; if C be taken away, E will collapse perfectly, the apparatus being in good order. As C enters the vessel A, the divergence of E will increase, until C is about three inches below the edge of the vessel, and will remain quite steady and unchanged for any greater depression. This shows that, at that distance, the inductive action of C is entirely excited upon the interior of A, and not, in any degree directly on external objects. If C be made to touch the bottom of A, *all* its charge is communicated to A; there is no longer any inductive action between C and A; and C, upon being withdrawn and examined, is found perfectly discharged. * * * * If C be merely suspended in A, it acts upon it by induction, evolving electricity of its own kind on the outside of A; but if C touch A, its elec-

tricity is then communicated to it; and the electricity that is afterwards on the outside of A, may be considered as that which was originally upon the carrier, C. As the charge, however, produces no effect upon the leaves of the electrometer, it proves that the electricity *induced by* C, and the electricity in C, are accurately equal in amount and power."

He next proceeds to show that, no matter at what depth C is placed in A, short of touching it, the divergence of the leaves of the electrometer is the same; and that "if P C be held eccentric, and near to the side of the ice-pail, in one place, so as to make the inductive action take place, in lines, expressing almost every degree of force in different directions, still the sum of their forces is the same constant quantity as that obtained before; for the leaves alter not. Nothing like expansion or coercion of the electric force appears under these varying circumstances."

Faraday expanded the experiment by placing in the first pail three others, each insulated from the other, at the bottom, by plates of shell-lac, and a space of air intervening between each. The details of the experiment need not be repeated here; the results were precisely as in the preceding one; and Faraday thus sums up the whole:—

"Thus a certain amount of electricity acting within the centre of the vessel, A, exerts exactly the same power externally, whether it act by induction through the space between it and A, or whether it be transferred by conduction to A, so as absolutely to destroy the previous induction within.

* * * * * * *

"Hence if a body be charged, whether it be a particle or a mass, there is nothing about its action which can at all consist with the idea of exaltation or extinction; the amount of force is perfectly definite and unchangeable; or to those who, in their minds represent the idea of the electric force by a fluid, there ought to be no notion of the compression or condensation of this fluid within itself, or of its coercibility, as some understand the phrase. The only mode of affecting this force is by connecting it with force of the same kind, either in the same or the contrary direction. If we oppose to it force of a contrary kind, we may, by discharge, neutralise the original force; or we may, without discharge, connect them by the simple laws and principles of static induction; but away from induction, which is always of the same kind, there is no other state of the power in a charged body; that is, there is no state of static force corresponding to the terms *simulated* or *latent* electricity away from the ordinary principle of inductive action; nor is there any case where the electricity is *more latent or more disguised* than when it exists upon the charged conduction of an electrical machine, and is ready to give a powerful spark to any body brought near it."

With the latter quotation of the views of Faraday in regard to induction, we shall conclude the separate description of the phenomena resulting from the exhibition, development, or disturbance of what is technically called static electricity. In the preceding pages, the beginner in the science has been put into possession of all its leading facts; the method of constructing, managing, and using the apparatus requisite in the pursuit of this interesting branch of experimental philosophy—interesting not simply in the laboratory or lecture-room, but equally so, on the large scale, in nature.

The preceding pages are necessarily introductory to the study of the phenomena of electricity as evolved by chemical action; and, to a certain extent, the facts and theories of one branch of electrical science are identical with those of the other. But certain differences exist, some of which have already been pointed out, whilst others remain to be considered. The general principles, however, are not only analogous, but identical. Hence the necessity of a full acquaintance with the laws, facts, theories, and other circumstances or conditions of static electricity, before we attempt to enquire into those of the dynamic force.

There is a great analogy between the statics of pure mechanical science, as shown in the resolution, composition, &c., of force, and static electricity; whilst a similar analogy subsists between hydrodynamics and the laws of current electric force. To some extent such analogies may prove unreal or delusive; but the extent of error will depend rather on the over-exercise of the imagination than in that of the judgment. The great unity that subsists between all branches of the science of nature induces us to seek for such analogies; and if we do not make too liberal, or too indiscreet use of them, they serve greatly to connect one series of facts with another, and lay at the foundation of proper generalisation.

CHAPTER VII.

VOLTAIC ELECTRICITY; ELEMENTARY PRINCIPLES; APPARATUS, ETC.

THERE is no branch of experimental science that presents to the student such interesting and brilliant results as that of voltaic, or current electricity. Its study, abstracted from the beautiful results that the electric current affords, interests both the philosopher and the popular taste. Its applications in the electric light, the electric telegraph, and electro-metallurgy, are as wonderful as they are useful.

About ninety years—namely, from 1790—have elapsed since Galvani first laid the foundation of Galvanism, as this mode of obtaining electricity used to be called; although, from the great aid that Volta gave to the study of the science, it is now almost universally called by his name. Galvani's early results have been variously described by different writers, and we forbear to give further currency to various statements that have been made as to the steps that led him to discover the new mode of producing electrical force. Without doubt, most of the history of the discovery is little better than fabulous, and scientifically romantic, and therefore it would be unwise to trust to uncertain *data.* Suffice it to say, that Galvani seems to have been impressed with the idea, entertained to prejudice, that animal electricity was the source of the effects he observed—the agitation of a frog's leg on contact with two metals. "He imagined the source of the electricity to be the animal itself, and that the metals were only efficacious in affording a conducting channel to this electricity." * * * "He assumed the brain [of the animal] to be a source of electric influence, which was distributed to all parts of the body. * * * The nerves Galvani believed to have the functions of electric dischargers, * * * and that a metal might be caused to assume the function of a nerve."

Volta attributed the effects that Galvani had observed to the contact of different metals. Hence arose what is known, in connection with this branch of science, as the celebrated "contact theory," the confutation of which, by Faraday, will receive especial attention in our future pages. Fabroni imagined that the animal contractions, caused by the contact of two different metals with the nerves and muscles, depended on the effects of heat developed by the oxidation of the metals employed. But we need not here continue to relate the various hypotheses that were offered as explanations of the phenomena of muscular contractions first noticed by Galvani, as, by the ruthless hand of experiment, as wielded by Faraday, all such theories came to an untimely end.

We therefore at once proceed to consider the practical bearings of this branch of science, and first notice how a current of voltaic electricity is produced. In the previous pages we have almost exclusively considered *static* electricity; that is, the force in a state of equilibrium, out of that state, and returning to that state: we now turn to what has not been inaptly termed the current force; and that has also been denominated *dynamic* (force-giving) electricity. But here we must caution our unscientific readers against making any great distinction between electricity developed by friction, and that produced by chemical action. Their effects are identical in all respects but one. Frictional electricity affords the force in an enormous amount of *tension*, or intensity (see *ante*, p. 205, *et seq.*); that is, electricity so generated can overcome obstacles of non-conducting bodies, such as air, &c., &c.; whilst the electricity generated by chemical action, has little power in that respect. On the other hand, voltaic electricity has enormous *quantity;* that is, it can affect good conductors, such as the metals, to an extent that all our artificial means of producing frictional electricity are utterly incapable of. At p. 205, *ante*, we have shown that a voltaic pair, consisting of a wire each of zinc and silver, or platina, develop a greater *quantity* of electricity than the most powerful flash of lightning; but, as previously shown, the power of electricity, as produced by chemical action, is very trifling as regards its intensity, even in the form of battery in which upwards of 10,000 pairs have been employed.

We must now explain the methods by which voltaic electrical phenomena are manifested, whether in a small or large degree.

If a copper nail be driven into a piece of clean zinc, and exposed, out of doors, to the action of the atmosphere and moisture, in the course of a short time the copper nail will seem to have eaten its way into the zinc. Whilst the nail shall have only become slightly darker in appearance, all the zinc in contact with it will have become rotten, owing to the oxidating influence of air and moisture; a new compound will have been formed, called the *oxide of zinc*, arising from chemical action, the oxygen in the atmosphere and the moisture having combined with the zinc to form a new compound. At the same time, by proper means, it might be discovered, that not only had a chemical change taken place, but also that, simultaneously, a certain amount of electricity was generated.

But a still more convincing proof of the production of an electric force or current, is found in the following simple experiment:—If a half-crown be placed on one side of the tongue, and

a piece of zinc on the other, until the two metals touch no effect whatever will be experienced on the tongue. But if, whilst the metals are resting on the tongue, their two extremities be brought into contact, a peculiar pricking sensation, and a metallic taste, will be perceived on that organ—effects due to the same cause, but separately manifested. The pricking sensation on the tongue arises from an electric shock, because the moment the two metals get into contact, an electrical current is generated. This arises from the chemical action of the acid and water of the tongue on the zinc; and this chemical action is the cause of the second effect —namely, the metallic taste.

In this simple and extremely elementary experiment, the following facts should be noticed; they are, indeed, the basis of the science of voltaic electricity:—1st. If two half-crowns be placed, the one under, and the other over, the tongue, and they be brought into contact at their other edges, *none* of the effects that we have named can be produced; and also, if two pieces of zinc be similarly employed, no results accrue. 2nd. It is evident, therefore, that a difference of some kind must exist in the two metals; and this is explained by the fact that the silver undergoes no chemical change whatever, whilst the zinc does. 3rd. It is, therefore, evident that chemical action on the zinc must be the cause of the effects produced; for mere contact of two similar metals has no result. 4th. If the tongue be perfectly dry, no effects are observed: it is only when that organ is wet that the shock and metallic taste are afforded. Lastly, it is evident that the shock must be that of some force acting on the nerves of the tongue; and which, as we shall shortly show, is electricity, that, generated, on a large scale, by analogous means, is capable of producing the most exalted effects of heat, light, magnetism, &c., &c.

But a much more ready and distinctive means of studying these phenomena may be obtained as follows:—If a piece of sheet copper, of any thickness—say an inch wide, and six inches long—and a piece of zinc of the same size (but first *amalgamated* by rubbing it with a little mercury in a plate, with some dilute sulphuric acid, until the surface of the zinc is brightly polished), be put into a glass jar filled with eight parts of water, and one of strong sulphuric acid, no effect whatever is produced so long as the two metals are kept apart from each other. But the instant they are allowed to touch, whether inside or outside of the water, a torrent of gas will arise from the surface of the *copper* plate. If the metals be separated, this effusion of gas will instantly cease, to be renewed at the moment the metals are again allowed to touch each other. It is evident, therefore, that two circumstances attend, at least, this experiment. The first is the necessity of *some* kind of contact between the metals, but which, as we shall subsequently show, need not be metallic; and the second is, the evidence of chemical action. Moreover, it will be noticed, in respect to the latter, that the zinc becomes rapidly dissolved in the liquid, whilst the copper remains unchanged; for the latter, if weighed after carrying on the experiment for some time, will not vary; whilst it will be found that, by degrees, the whole of the zinc will be dissolved away. It will be discovered that it has produced the sulphate of zinc, which will be held in solution in the liquid; and from the latter the oxide of zinc may be recovered, and even the metal itself, by proper chemical means that we need not here describe.

Further than this, however, we shall find that if, instead of letting the two plates touch each other, either in or out of the liquid, if their outer edges be joined by a very fine steel or platina wire, the latter will be instantly melted, becoming, at the same time, white-hot. This shows that, besides chemical action, a calorific, or heat-effect, is also produced, together with the production of light. By means of what is called a galvanometer (that will be hereafter described), it will be found, also, that electric and magnetic effects are simultaneously afforded by this simple piece of apparatus: it forms what is known, in science, as a simple and single voltaic pair or cell, and shows the production of heat, light, electricity, and magnetism, generated by chemical action.

We next turn to examine what is the nature of that chemical action.

First we take the office of the acid. If only common river water be employed in the experiment, no gas will appear on the surface of the copper plate, or, at least, not until a long time has elapsed; but the addition of the sulphuric acid increases the *conducting power* of the liquid (see *ante*, p. 217), and so facilitates the production of chemical action. But it is only the *water* that undergoes decomposition, and not the acid. Every 9 grains of pure water contain 8 grains of oxygen and 1 of hydrogen. In the elementary experiment just referred to, the 8 grains of oxygen combine with 32 of zinc to form 40 of the oxide of zinc. As this is formed the sulphuric acid dissolves the newly-formed oxide, to produce 72 grains of sulphate of zinc, 40 of the acid requiring 32 of the oxide to neutralise each other.

The hydrogen finds nothing in the liquid or the metals to combine with; and, consequently, in this form of apparatus it passes off in gaseous bubbles, which may be set fire to by a lighted match as they rise to the surface.

We therefore find that two metals, acted on dissimilarly, or the one not at all, in a fluid capable of being decomposed, produce, together with the chemical action, dependent on their being connected by a conductor, light, heat, electricity, and magnetism.

It has been stated that a solid metallic conductor is not necessary to excite the action; and although, in our future pages, we shall have to discuss the merits of the contact and chemical theories, it will be desirable that we should here prove that contact, *metallically*, is not absolutely necessary, and only desirable for the purpose of showing the effects of the preceding experiment in their fullest condition.

If a thin copper wire be soldered to each of the plates, and the ends of the wires be brought into contact, precisely the same effect results as is discovered on the plates being made to touch each other by their edges, either in or out of the liquid. But if the end of each wire, instead of being made to touch, be immersed close to each other, though not touching, in a strong solution of sulphate of copper, to which a little sulphuric acid has been added, new phenomena will be evinced. Not only will the evolution of hydrogen from the copper plate go on as when the plates were placed in contact, either by themselves or by the wires touching each other ; but, in this new arrangement, it will be perceived that the end of one of the wires immersed in the copper solution will gradually diminish, becoming dissolved away, whilst the other will increase in size, and be coated with a salmon-coloured deposit of copper, derived from the solution of the other wire. That wire which proceeds from the zinc plate *increases* in size, whilst that proceeding from the copper plate decreases. We hence discover, that the chemical action of the pair, in the jar, is propagated by the wires into the solution of the copper salt. In other words, we have a *current* force, that continues in an uninterrupted circulation so long as the action of the water on the zinc, in the large jar, is maintained. To the phenomena of heat, light, electricity, and magnetism, thus generated by a pair of dissimilar metals, we have, therefore, to add that of chemical action, developed *external* to the pair of metals and the jar containing them.

In the latter experiment, it must be noticed that the end of the wire proceeding from the metal that is *dissolved in the jar*, *increases* in size in the copper solution ; whilst the wire that proceeds from the metal *not dissolved* in the jar, *decreases* in the copper solution, becoming ultimately dissolved away. Here we may therefore explain, that the ends of the wire, and the plate to which each is attached, must be designated by opposite electrical terms. The zinc plate in the jar is *positive*, but the terminal of its wire in the copper solution is *negative*. The copper plate in the jar is negative to the positive plate of zinc facing it ; but the end of the wires proceeding from the copper in the solution of the copper salts is *positive :* hence, whether in the jar or in the copper solution, the plate or wire that undergoes solution is positive ; whilst, within certain limitations that, for simplicity's sake, will be here omitted, the negative plate, or pole, does not undergo solution.

An elementary view may be thus obtained of the means of producing electricity by chemical action ; although our readers must, for the present, take the fact for granted ; because it requires a much more powerful arrangement than that we have described, to produce similar phenomena to those evinced by electricity excited by friction. As we proceed, however, the identity of the electricities afforded by mechanical and chemical action, will be recognised to an absolute certainty.

The simple arrangement of a plate each of copper and zinc, with the conducting wires, constitute what is technically termed a galvanic pair, or single cell. But, by universal consent, the name of Volta is now substituted for that of Galvanic ; and we shall therefore, in future, adopt that custom.

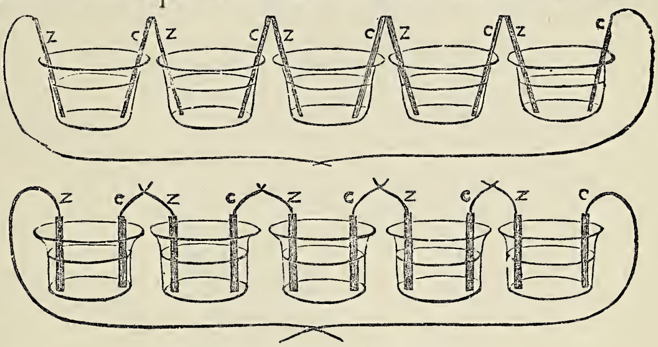


Fig. 132.—Couronne de Tasses.

By uniting several such cells together, a galvanic or voltaic battery is produced. The preceding cut represents such an arrangement. In the upper portion the plates are represented as in contact with each other at their outer edges ; and, from the last copper and the last zinc, a wire extends, between the ends of which (shown in contact in the cut) all the phenomena of voltaic electricity are manifested. In the single, as in any number of cells, the current of electricity is popularly explained as passing from the zinc to the copper ; and, in the compound series, it passes by metallic contact from the copper of one cell to the zinc of the next, and finally returning by the terminal or end wires to the battery again, whether those wires be in contact metallically, or immersed in a conducting or decomposing solution. The lower half of the preceding cut represents the metals as connected together by wires soldered to each plate—a method all but universally adopted in all voltaic batteries of modern construction. The following cuts represent, respectively, single cells of

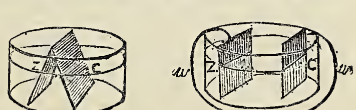


Fig. 133.

the two forms of batteries. On the left hand the metals are shown in contact by their edges ; whilst, in the right hand cut, they are connected by means of wires. When the two end wires of a voltaic battery are in contact, what is termed a closed circuit is produced.

Until we enter into an examination of the theory of the voltaic battery, and its effects, it

will be convenient for us to use the term "current" to express the passage or effects of the force generated by the means already, or to be, pointed out. Not that it is correct so to do, but it will save much circumlocution; and, for the same reason, we have used several popular phrases—such as "fluid," "struck," &c., &c.—in the preceding pages.

The first form of voltaic battery was the pile devised by Volta. Although an extremely imperfect instrument, it is readily constructed. A number of zinc and copper plates—say four inches square—are soldered together in pairs; that is, a plate of copper is soldered to one of zinc. A number of pieces of woollen cloth or leather—or, indeed, almost any porous material, even brown paper—are cut of a size a trifle less than the metal plates; and these pieces are to be soaked in a strong solution of common salt. The metals are then piled up with the pieces of cloth, in the manner shown in the annexed cut; C representing a copper, and Z a zinc, plate; whilst W is the piece of salt-wetted cloth. If a wire be soldered to the last top and bottom plates, and the edges of one be rubbed on a file, whilst the other wire is twisted round the file itself, bright sparks will be seen; and, if about fifty alternations or pairs be employed, and the hands be wetted with salt and water, a smart electric shock will be perceived.

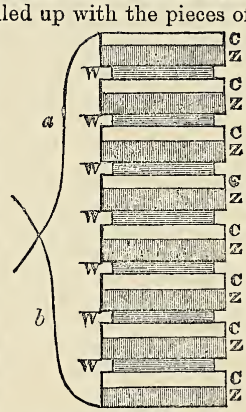


Fig. 134.—The Pile.

We must here point out two distinctive requisites of a voltaic battery: they are *quantity* and *intensity*, already referred to at p. 205, *ante*, in connection with the subject of frictional electricity. When quantity is required, as for melting wires, producing large effects of chemical action, brilliant light for the combustion of metals, the plates of the battery are made of large size, although their number may be comparatively few; for the larger all the plates of the battery are, the greater is the quantity of electricity produced. But when we wish to imitate the effects of frictional electricity, the size of the plates becomes of less importance, whilst it is absolutely necessary to employ a large number. Thus a *single* pair of plates, of large size, will melt metals with ease, but would not in the least affect the gold leaves of the electrometer; whilst, on the other hand, a hundred small plates would diverge the leaves of the electrometer, but would not melt metal wires.

Again, the quantity of the battery is increased by using strong acid solutions, and bringing the plates as near to each other as possible. The reasons of these facts, and the laws that govern the phenomena, will be fully inquired into hereafter. We merely state them here, so that our future remarks may be understood.

The inconveniences of the voltaic pile are great. It is liable to be upset; and, not only so, the insulation of each set of plates from the rest becomes vitiated by the liquid squeezing out of the cloth, and so forming a conducting medium from the top of the plate to the bottom.

The first great improvement was that introduced by Mr. Cruickshank, in the form of battery that still bears his name, and is frequently used in a modified state for telegraphic purposes in our day. This instrument is represented in the following cut. The exterior of


Fig. 135.—Cruickshank's Battery.

the battery is an oblong trough of wood, mahogany being the best for the purpose. Pitch and resin are melted together, and run into the box, so as to coat all its internal surface to the thickness of about half an inch. Plates of copper and zinc are soldered together at their edges. These plates are heated and forced into the resin coating of the trough, so that they may be at a distance of—say half an inch apart, as shown in the above cut. All the coppers face one end of the battery, and the zincs the other; and thus in each cell a copper surface faces a zinc one; the plates being fixed in the zinc in such a manner that they form separate water-tight cells, which are filled to within an inch of the top with a solution of common salt, sulphate of soda, or a dilute solution of either sulphuric, nitric, or hydrochloric acid, if extra *quantity* be required for heating-effects. A copper wire attached to the last plate, at either end of the battery, as shown by Fig. 134, *ante*, completes the arrangement. With fifty cells in a trough, a spark, the ignition of wire, and a shock may be obtained. The amount of light and heat developed will be in proportion to the size of plates used; whilst the intensity of the shock will be in proportion to their number, for reasons already given.

But this form had its inconveniences. At the time of its invention, the art of amalgamating the zinc, as described at p. 226, *ante*, was unknown; and, consequently, if strong acid solutions were used, the zinc plates soon were eaten away or dissolved. The battery, of course, then became useless.

The next improvement was that of Dr. Babbington, and is represented in the following cut. In this instrument the plates of copper and zinc were suspended from a wooden frame, each being kept separate; the copper of one cell, however, being connected with the zinc of the next by means of a copper strip, in place of the metals being soldered together. This method of connection is illustrated in Fig. 132, *ante*, which represents the form of battery called the *Couronne de Tasses* ("circle" or "crown of cups"). The plates of Babbington's battery could be raised *en masse* out of, or lowered into,

a porcelain trough, containing the exciting liquid. This trough is seen at the lower part of

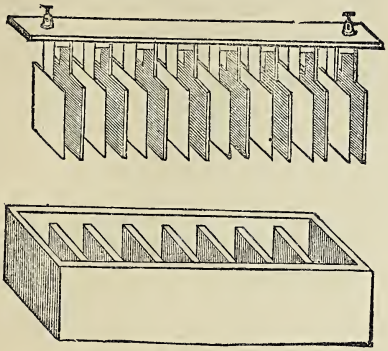


Fig. 136.—Babbington's Battery.

the above engraving. By thus being able to remove the metals from the acid liquor, and in the then absence of any knowledge of the use of amalgamating the zinc, the waste of this metal was greatly lessened, and the length of time that the battery could be used was prolonged.

An improvement on this was invented by the celebrated Wollaston. It will be evident that, in all the preceding arrangements, only *one* surface of the copper and zinc plates faced each other, and the other surface was of no electrical avail. But by doubling the copper, in the form represented in the annexed cut, it is evident that both faces of the zinc could be brought into action; and hence, for the same size, the quantity of the battery power was doubled. It is true that the outer surfaces of the copper plate were useless; but, as they were not acted on, that was a matter of no importance beyond their first cost.

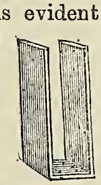


Fig. 137.

In all these forms of batteries, however, a great objection existed. The copper surface became coated, at the moment the terminal wires were connected, with bubbles of hydrogen. These covered the metal with a non-conducting gaseous surface, that, in a few seconds, reduced greatly the power of the battery. Besides, as the zinc became dissolved gradually in the acid, it formed a solution of sulphate of zinc; and when the water in the troughs became saturated with this salt, all action ceased. We can well remember the annoyance thus occasioned, whether in the laboratory or the lecture-room; but many years elapsed before any radical improvement was made. Mixtures of nitric acid and sulphuric acid were employed, so that the oxygen of the former might, during decomposition, be united with the liberated hydrogen on the copper plate surface; and thus, to some extent, the evil of gaseous adhesion was mitigated: at the same time, however, the zinc plate was injuriously acted on; and so the remedy was almost as bad as the complaint.

Writing from memory, we believe that it was in 1836 when Professor Daniell, of King's College, London, brought out his "constant" or "sustaining" battery; by which we mean, that he invented an apparatus that could afford an equable and powerful current of voltaic electricity for hours, in place of the results obtained from the batteries we have described, and that rarely lasted as many seconds.

For the present we cannot enter into a full description of what, in the technicalities of the science, is termed "secondary action;" but its principles may be thus briefly explained. If a polished piece of steel, as the blade of a knife, be dipped into a mixture of sulphuric acid and water, bubbles of hydrogen will abundantly rise to the surface, owing to this gas being set free, whilst the oxygen of the water combines with the iron to afford oxide of iron; the latter becoming dissolved in the acid, and forming sulphate of iron. But if, before dipping in the steel, the acid solution be made to dissolve as much as it can take up of sulphate of copper, and the blade be dipped into the resulting solution, *no gaseous hydrogen* will be given off. Instead of this, at the instant of immersion, the iron or steel will become coated with a salmon-coloured precipitate, which is pure metallic copper, derived from the copper salt in solution.

The effect that takes place is as follows:—The copper salt is composed of sulphuric acid and oxide of copper. The hydrogen that is evolved from the steel plate on immersing it in the solution is instantly seized on by the oxygen of the copper salt, and unites with it to produce water; whilst the copper, being set free, is precipitated as a metal on the iron surface; hence the reason that no bubbles of gas appear.

Applying this principle in another experiment, the *rationale* of Dr. Daniell's battery may be still further illustrated. Thus, if the copper and acid solution, just named, have immersed in it a plate each of copper and zinc, no change will occur to the copper, but the zinc will be gradually dissolved away, whilst a spongy coat of copper will form on its surface. But if the two metals be brought into contact by their edges or by a wire, as represented in the right-hand cut at p. 227, Fig. 132, *ante*, then a *deposit of metallic copper will at once commence on the surface of the copper plate, and will continue to be produced as long as any copper salt remains in the solution.*

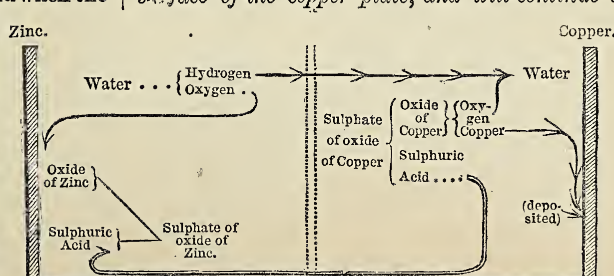


Fig. 138.—Daniell's Battery.

In a Daniell's battery copper and zinc are the metals employed, and the process of decomposition that goes on is represented in the preceding engraving, which is sufficiently explicit of itself, as it merely illustrates the principles just enunciated.

But another feature of great importance in Daniell's, and all subsequently invented constant batteries, is the use of a diaphragm, for the purpose of separating the two fluids employed. It is represented by the dotted line in the preceding cut. The object of the diaphragm is to keep the copper solution alone with the copper, and a solution of acid and water alone with the zinc; for, as we have seen in the preceding experiments, if the copper solution gets into contact with the zinc, it speedily precipitates a spongy coating of copper on that surface, that would lead to great waste and loss of battery power.

The most usual form of Daniell's battery is illustrated in the annexed cut. C represents an external copper cylinder, of course, closed at the bottom; on to it is soldered a wire and binding-screw, so that the copper of one cell may be attached to the zinc of another by means of a copper wire. T is a small perforated tray, that is hung inside the copper cylinder, and is intended to hold crystals of sulphate of copper, that are supplied, from time to time, to replace the copper salt decomposed by the action of the battery. D is a porous cylinder, resting on C, and encircled by the tray, T. The best material for this cylinder is unglazed ware of good baked clay. It should be sufficiently porous to allow of a perfect conduction by moisture between the acid and copper solution, and yet not so much so as to permit of their mixture. One of the best tests is to apply the tongue to the outer surface of the porous pot, and if that organ adhere strongly, and if, after its removal, all signs of moisture instantly disappear, then the pot is fit for its purpose.

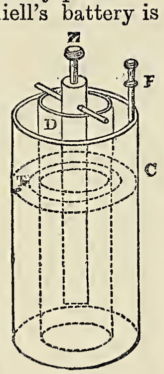


Fig. 139.

Within the porous pot, a slip, or rod, of amalgamated zinc, Z, is placed, and, by fixing a binding-screw at the top, it can be connected with the copper of another cell by means of a wire. The annexed cut shows a section of the upper portions of a Daniell's cell; C C being the copper cylinder, P the perforated tray to hold the crystals, and Z the rod or slip of zinc.

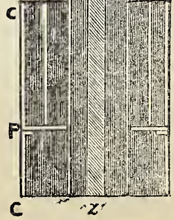


Fig. 140.

To charge such a cell we proceed as follows:—One part, by weight, of strong sulphuric acid is to be mixed in an earthen vessel, with eight parts, by weight, of water: if the mixture is made by measure, then in an eighth of sulphuric acid nearly twice as much will be used, because the specific gravity of the acid is nearly double that of water. An *earthen* vessel must be used, because of the great heat generated. The acid solution having become cool, may be employed to fill the porous pot that contains the zinc. The rest of the acid solution—if hot so much the better—is to have stirred up in it crystals of sulphate of copper as long as it will dissolve any, and this solution is then to be poured into the copper cylinder *outside* of the porous pot. The tray, T or P in the preceding engravings, is then to be filled with crystals of the copper salt.

The battery being thus charged, if a wire be attached each to the copper and zinc plates, and these two wires be brought into contact, a current of electricity will be generated, passing from the zinc, through the liquids, to the copper, and, at the same time, no hydrogen will be evolved from the latter. On the contrary, according to the principles already explained, the copper salt will be decomposed, and pure metallic copper deposited on the copper surface. As long as fresh crystals are added to the tray, the action of the battery will go on, except that the acid solution next the zinc will require renewal so soon as it is saturated with that metal.

This battery is of great value to the experimentalist, on account of the equable nature of its results. We have frequently had one at work, in chemical decomposition, for twenty-four to thirty hours continuously, without its requiring any attention. In fact, although much less powerful than many batteries that have to be described, it has advantages of constancy in action far exceeding any other.

Many modifications of form have been made in respect to Daniell's battery. The diameter of the cylindrical form of this battery should be about 3½ inches for the copper vessel, and varying, in height, from 6 to 22 in.; the porous pot may be about 2 inches in diameter, and the zinc "plate" either a cylindrical rod, 1 inch diameter, or, still better, as a matter of convenience, a strip of the metal, an eighth of an inch thick, 1 inch wide, and 2 inches higher than the copper cylinder.

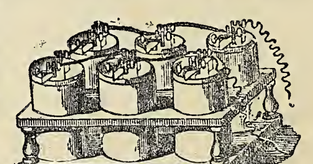


Fig. 141.—Smee's Battery.

Fig. 141 represents a series of six cells of Smee's battery described in a subsequent page.

In place of the latter, the following may be adopted for the circular form of Daniell's cell:—Outside is a porcelain, well-glazed pot, containing the copper solution; and inside this a piece of sheet copper, 11 inches wide, coiled round so as to form a cylinder of about 3½ inches in diameter, to which a strip of copper is to be soldered or riveted, to make connection with another cell. The rest of the arrangement is precisely similar to that already described. In this form, the outside porcelain pot takes the place of the copper vessel, which has the occa-

sional inconvenience of leaking. On the other hand, if the outer porcelain vessel be not of the best material, the copper salt will soon destroy it by permeating its substance.

To a certain extent, the porous pots of Daniell's battery are liable to become destroyed from two causes. Gradually the sulphate of zinc formed, crystallises ; and it has so powerful a mechanical effect on the texture of the pot, that it will break it into pieces. For this reason, it is necessary that, in whatever form of battery a porous pot is employed, it should be frequently placed in warm water, to dissolve out any saline matter that might crystallise in its pores. If, after using such a pot, in a Daniell's or other battery, it be left in the open air for a few hours, its surface will become coated wlth needle-like crystals of sulphate of zinc ; and if the pot be so left for a few days, its fracture, especially in summer-time, will be sure to occur.

Daniell's battery may be fitted up with flat cells, the copper plate being doubled outside of the porous pot containing the zinc. But no advantage arises from such a method, except that of saving space on the lecture-table. At the present day, however, no one would attempt to use an extended series of Daniell's battery for such a purpose, because we possess instruments far more powerful, in respect to extent of surface, or space-covering, such as Grove's, &c., that will be presently described. The great advantages arising from the use of a Daniell's battery, are only esteemed in the laboratory, or by the electrotyper ; and the latter frequently discards it.

Before proceeding further in our description of voltaic batteries, some other principles must be enunciated as governing their construction. Hitherto we have only mentioned copper and zinc as the metals usually employed for constructing such instruments. Practically, no other metal is ever employed as the positive (see *ante*, p. 227) element than zinc, in an amalgamated state, because it fulfils all necessary conditions for that portion of the voltaic battery : but it must be borne in mind, that the further the affinities of the *negative* metal employed are from those of the positive in a voltaic cell, the greater are the results produced. Thus if a plate of silver, platina, or gold be employed in place of one of copper in the elementary experiments detailed at p. 226, *ante*, a far greater effect will result than by the use of copper as the negative element. If we could employ potassium as the positive element in a voltaic battery, with platina as a negative element, in solutions affording available oxygen or chlorine, we might, and most probably should, get the most powerful arrangements, in all respects, that could be desired. But this is impossible, because the potassium has such an affinity for oxygen as to unite with it in an almost explosive violence, if the latter element be presented to it in the form of water. But retaining the more convenient and manageable zinc, we increase, as just stated, the quantity and intensity of the voltaic current just in proportion as we adopt for the negative element a metal having proportionably less attraction for oxygen or chlorine, according to the exciting solution employed in the battery. Other concomitant and ruling conditions will be here presently named.

Dependent on these, and on the fact that strong nitric acid will part with its oxygen to nascent hydrogen, Mr. Grove, about forty years ago, brought out the most powerful voltaic apparatus that has yet been invented. In his arrangement, the negative metal, or element, is platina, and the positive is amalgamated zinc ; the latter is excited by a mixture of one part of sulphuric acid added to from five to eight parts of river water. On the side of the platina, and separated from the acid liquid of the zinc by means of a porous pot, strong nitric acid is employed, or a mixture of sulphuric and nitric acids. The mechanical arrangements, in all other respects, are the same as in other batteries. Owing to the highly negative character of the platina, and the readiness with which the nitric acid parts with its oxygen, this form of voltaic battery far exceeds all others in its powers—omitting Bunsen's, or any form of charcoal battery, together with those of passive iron, both yet to be described. Grove's nitric acid or platina battery affords a current at least five times greater, in all respects, than any earlier form of battery, taking into question the surface of the metals exposed, and the space occupied.

The usual form, and that which we shall first describe, of Grove's battery, is that of the flat cell. The annexed cut represents such an arrangement in section. *a a* is a flat porcelain vessel—say, for example, 4 inches high, $3\frac{1}{2}$ inches broad, and having a width of $1\frac{1}{2}$ inch ; *b b* is a porous pot, a little less in breadth than the outer pot—say 4 inches high, 3 inches broad, and half an inch wide. In the outer porcelain pot is a plate of amalgamated zinc, bent, before amalgamation, into the form indicated in this cut, *z* ; but more plainly illustrated by the shape shown at p. 56, Fig. 48, *ante*, so that it may present two surfaces to the platina ; *p* is a piece of thin platina foil, about $4\frac{1}{2}$ inches long and 3 broad. It is placed inside the porous pot, with strong nitric or nitric and sulphuric acids ; whilst, as before stated, dilute sulphuric acid is the charge employed on the zinc side. The platina, in a series of cells, is connected, by means of wires and binding-screws, with the zinc of a following cell, in the usual manner.

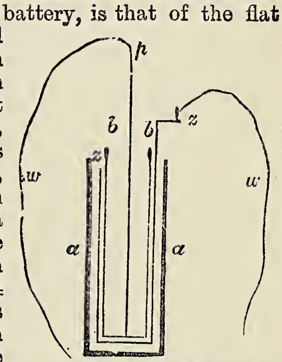


Fig. 142.—Grove's Battery.

Such an arrangement, extended to thirty or forty cells, of the size just named, produces most magnificent effects of light and heat. With fifty cells, the light produced between charcoal

points is equal to from 1,000 to 2,000 wax candles burning at once. Several feet of iron or steel wire may be instantly melted; and, in fact, all the phenomena of the voltaic current are manifested in the most striking manner.

As just stated, the flat-cell form is that usually adopted; but for all ordinary purposes we much prefer the following plan; for the effects last longer, owing to the large amount of nitric acid that can be used at a time. An external porcelain pot, of any chosen height, is used, to contain a cylinder of zinc, of the shape shown in the annexed cut: *a* being the cylinder of zinc, which should be amalgamated after being bent; *b* is a strip of copper, half an inch wide, and soldered to *a*, so as to form a connection with the platina plate of a second pot. The platina may be either united to the copper strip, by soldering, as shown in the annexed cut, at *a*, or by binding-screws, in the usual manner. Inside the zinc cylinder a circular porous pot is to be placed, such as that described as used in the form of Daniell's battery, illustrated by Fig. 139, at p. 230, *ante*. The porous pot containing the platina is charged by nitric acid; and the porcelain pot containing the zinc by dilute sulphuric acid, as in the flat-cell arrangement.

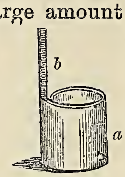


Fig. 143.

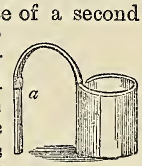


Fig. 144.

The battery is charged as follows:—Each porcelain and each porous pot receives, *respectively*, its charge of dilute sulphuric and strong nitric acids, the pots being arranged side by side, in series of ten. A zinc cylinder, without the platina, is introduced into the first pot; then another zinc cylinder is introduced into the second pot, with its platina resting in the nitric acid of the *first porous pot*; that is, the porous pot first in the series. This arrangement is continued throughout the whole series; the platina attached to any pot resting in the porous pot of the preceding one. Thus a last platina and a first zinc will be left free; and to these the conducting wires are affixed by soldering, or by binding-screws.

It will be thus seen, that, in the mode of arranging Grove's battery, only the form, and not the principle, is altered. The advantage of the method is, that although a small loss of power occurs from the greater distance of the metals from each other (see *ante*, p. 228), still almost any quantity of the acid may be employed; and, consequently, whilst in the flat-cell form, the acids would be exhausted in half-an-hour, the cylindrical mode of arrangement will afford uninterrupted effects for hours; in fact, just in proportion to the quantity of acids employed. For the purpose of affording the electric light, we have kept the cylindrical form just described in action for from four to six hours; whilst the utmost the flat-cell method would last did not exceed forty minutes, and then some of the cells would get so hot, near the centre of the series, as to boil away the acids, and, consequently, stop the action.

Platina is, of course, a very expensive metal, and many attempts have been made to substitute others for it; but, as every other metal but gold is rapidly acted on by nitric acid, none could be so employed. Charcoal, however, is not only a good conductor of electricity, but, at the same time, may be employed as an efficient substitute for platina in a nitric acid battery. It may be either used in the flat or cylindrical form, as already described; indeed, the carbon battery in nowise differs from the platina battery just described, except in the substitution of another material for the negative element or plate.

When first introduced into use by the celebrated chemist, Bunsen, the charcoal plates were made by mixing together powdered coke, of the hardest kind in powder, with strong syrup or oil. The paste so formed was made into cylinders, or plates, that were compressed into the desired shape. The mass so obtained was then exposed to a high heat in an oven, so as to decompose either the sugar or oil, and so to leave a solid plate of conducting charcoal. But now a kind of artificial graphite, found as a lining of gas retorts, and arising from the sublimation of carbon, is employed. It is exceedingly hard, and cut up into plates, &c., by the saw or lathe. In its effects, it is little, if at all, inferior to platina; and, as such, may be economically substituted for that metal.

In using the charcoal or carbon, however, several precautions are requisite. Its porosity tends to carry up the nitric acid by capillary attraction, and so it soon destroys all copper or brass connections. After a little use, each plate should be soaked for some hours in hot water, and then dried before a fire. We invariably so soak and dry the carbon plates after each time of using, and they gradually improve in their qualities by this treatment, for the iron, sulphur, &c., become thus removed. Before using the carbon plates for the first time, as received from the makers, they should be steeped for several hours in nitric acid and water, to remove a vast quantity of soluble matter, adherent dust, &c.; and then be well washed in a running stream of water. If this be neglected they will be useless, until, by wasting the acid in the battery, they have gradually acquired the requisite cleansing. Once, having neglected this precaution, and using forty plates just as received from the makers, we had the mortification of not being able to show one experiment at the lecture-table; although on the following night, after the plates had been steeped and washed, the effects were magnificent.

The platina of a Grove's battery similarly requires attention. All polished surfaces tend to acquire on them a film of air. This fact is illustrated by placing a sewing-needle, of small size, on the surface of some water in a basin. The needle, although seven times, at least, as heavy as its own bulk of water, will not sink, because the film of air attached to its surface is sufficient to float it. But if the needle be heated, and replaced on the water, it will instantly sink, because, by such means, the ad-

herent film of air is driven off. So, on the platina of a battery, a film of air gradually accumulates, and actually so covers the surface of the metal as to prevent the nitric acid from coming in contact with it. It is, therefore, advisable to make the platina plates red-hot before each time of use. This is easily done by holding them successively in the flame of a spirit-lamp until red-hot, when not only the air is driven off, but all dirt, acid, &c.

Another advantage arises from this. No matter what metal is subjected to the continued action of a voltaic current, it gradually becomes brittle, and platina forms no exception to the rule; hence the frequent breakage of platina foil employed in Grove's battery. But, by frequently heating it to a red heat, this cause of its fracture is entirely removed. For precisely similar reasons, the axles of locomotives, and all shafting, tend to break after long use, the molecular construction of the best fibrous iron, in the first instance, being changed into that of a crystalline and brittle condition. The age of a railway axle is therefore carefully noted; and after a certain mileage, it is detached, and heated for some time, to destroy the crystalline and restore the fibrous character, together with renewed tenacity.

Many years ago, it was discovered that iron, although at first rapidly acted on by nitric acid, suddenly became passive; that is, the acid ceased to act upon it; and, in that condition, ordinary, but especially cast-iron, may be substituted for the platina or carbon of the batteries previously described. When this fact was first published, we fitted up a small battery of iron-hoop, such as is used to bind bales of goods; and so long as the acid remained strong, the effect was scarcely inferior to that already described. We have, indeed, even used copper as the negative element with nitric acid; but this singular anomaly must be afterwards dealt with more fully, because it involves some important considerations in connection with the theories of voltaic electricity.

Cast-iron cells may be cheaply employed. For example, a cell of the same form and size as that represented at p. 230, *ante*, Fig. 139, as constituting a Daniell's battery, is cast in iron. The iron department is charged with a mixture of strong nitric and sulphuric acids, whilst the porous diaphragm, or pot, holds the zinc charged with dilute sulphuric acid. Such arrangements, from the cheapness of the iron compared with the cost of platina or carbon plates, may be made of a large size at an exceedingly moderate expense. It is known by the name of Callan's battery, from having been first extensively brought into use by that celebrated professor, at Dublin. The iron battery has also been much used for blasting purposes.

The preceding voltaic arrangements are those that give the greatest power, considering the surface of metals exposed, and the space occupied; but they are all attended with the great inconvenience of giving off a prodigious quantity of suffocating fume, produced by the evolution of various nitrogenous compounds with oxygen. In fact, to use a large battery of any of the nitric acid kind that have been described, in a close room, is highly prejudicial, not to say dangerous, to health, and may bring on hæmorrhage to an alarming extent on the lungs. It is always best, when using a large nitric acid battery, to have it placed either under a hood, affording abundant means of ventilation, or in the open air. A cast-iron nitric acid battery should always be kept in that condition when in

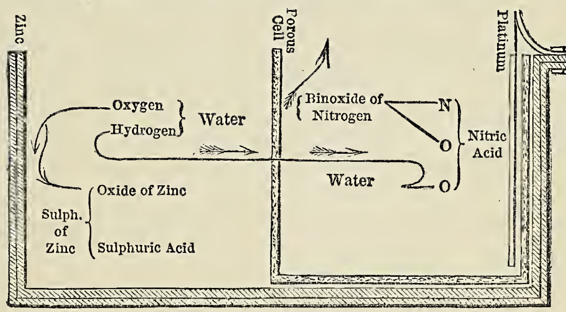


Fig. 145.

action, for the amount of fumes emitted is very great. The above diagram explains the reason of this.

On the right-hand side of the engraving, the words "binoxide of nitrogen" will be noticed. Now this gas results from the decomposition of the nitric acid next the platina plate; the acid becoming deoxidised by the nascent hydrogen that is given off; consequently, the binoxide passes off as an invisible gas. The moment, however, that it gets into contact with the oxygen of the atmosphere, it becomes oxidised; and, from being transparent and colourless, it is turned to a dark-red colour, and of a highly offensive odour, attaching to the clothes, &c. If breathed without admixture with the air in large quantities, it would speedily produce death; and hence the violent coughing and other effects that proceed from inhaling the fumes of nitric acid batteries. This vapour, again, destroys wires, binding-screws, and other connections; hence the nitric acid forms of battery are very expensive apparatus to work with.

We may notice a battery, suggested, many years ago, by Dr. Leeson, in which a solution of bichromate of potash and dilute sulphuric acid, mixed together, was employed. It never came into much use. The bichromate of potash cell now, however, largely used, is a modification of this arrangement. The negative plate is a piece of gas carbon, as in Bunsen's battery, and the positive plate a piece of zinc, with the usual binding screws, etc. As a single-cell arrangement, this form is now in much favour for medical and other purposes, and even in machines for obtaining electro-motive power.

Perhaps no battery that has yet been in-

vented has attained greater favour, in scientific, practical, and popular circles, than that of Mr. Smee, long distinguished in scientific research, and especially as having been amongst the first to enunciate guiding principles in the art of electrotyping. For the latter purpose Smee's battery was once extensively employed.

As in all other voltaic batteries, zinc is used for the dissolving, positive, or oxidised element. But, for the negative plate, Mr. Smee suggested a piece of pure silver plate coated with fine-powdered platina. This is easily done by immersing the silver foil or plate in a strong solution of chloride of platina, obtained by dissolving that metal in *aqua regia*, which is a mixture of nitric and hydrochloric acids. The platina is thus deposited as a fine black powder on the silver, forming on its surface a multitude of points, that cannot be distinguished by the naked eye, on account of their fineness.

By referring to p. 229, *ante*, it will be found, in our description of the early forms of the voltaic battery, that the great objection to these lay in the adhesion of the hydrogen to the surface of the copper, that coated the latter metal with a non-conducting surface. Now, the points of platina powder on the silver plate of Mr. Smee's battery get rid of this difficulty. He uses only one fluid—dilute sulphuric acid and water. The plate of silver is enclosed between two plates of zinc. In the following cut, *a a* represent the zinc plates, that are

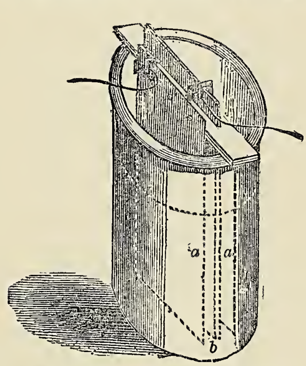


Fig. 146.—Smee's Battery.

connected together at the top, on a wooden frame; and *b* is the silver plate: on each of them connections are made in the usual way, by means of binding-screws and wires, and thus any number of cells may be connected together. The zincs are, of course, amalgamated.

As long as the connecting wires are kept apart, or, in other ways, the circuit is unclosed, no effect is evident in the battery. But the moment the circuit is closed, torrents of hydrogen gas escape from the platina powder, and the action is exceedingly energetic. For compactness, completeness, ease of manipulation, and freedom from annoyance, combined, this battery has no equal; and it is one that should be chosen in preference to any other by the beginner, for it requires not the least knowledge of the science to manage it.

Last in the list of the numerous forms of voltaic battery that may be now described, is one of cast-iron. The only form in which we have seen such a battery used or constructed, was that of a flat cell, six inches high, four wide, and an inch broad. Into this was placed an amalgamated zinc plate, edged with corks, so that it should not get into contact with the sides of the iron cell. The charge was one of strong sulphuric acid to two of water, by measure. The quantity afforded by this battery was enormous, so long as it lasted; but that was not of much duration; for the water became speedily saturated with iron and zinc salts, and thus the power rapidly diminished. The arrangement, however, is one that might be of much use for blasting; for which purpose we believe it was first brought out.

All the forms of batteries that have been described in the preceding pages have been subject to many modifications. Subsequently, we shall have to describe others now largely used in electro-telegraphy.

If a large quantity of electricity be required, a number of small cells may be so connected that all their negative and positive elements are joined together, so that fifty or any number of cells may be so arranged as to be, virtually, only one; for it will be evident, that if each positive plate be joined to all the others in a series, and, similarly, each negative, they will, consequently, all only act as if they were one cell of a size holding a pair of plates, having a surface equivalent to the sum of the series. Similarly, if a battery of fifty cells be arranged in pairs, it may be made of twenty-five cells, each equal, in effective area, to a surface of plate double to that of a single cell of the series. Thus two, three, four, &c., may be formed; and any desired amount of quantity, attended, however, with a proportionate decrease in intensity, can be obtained. The reason of this will be evidenced by perusing what was said at p. 229, *ante*, in respect to the effect of the size and number of plates in influencing the power of a voltaic combination.

We may conclude these remarks on the construction of voltaic batteries by giving some practical hints as to their management. A supply of sand-paper, sand, copper wire, and strips of the metal, binding-screws, files, mercury, &c., &c., is requisite. Nothing is more important for the success of voltaic experiments than clean surfaces, where connections are to be made. Such surfaces should, if small, be well rubbed with sand-paper, to perfectly polish them. If greatly tarnished, they may be washed with hydrochloric acid, which will instantly clean them. Some persons afterwards amalgamate the surfaces by washing them with a solution of nitrate of mercury, which is easily made by dissolving that metal in nitric acid in a bottle, and leaving an excess of the mercury at the bottom. When a little of this solution is rubbed over a clean copper surface, it gives it a white polish. But this method, if persevered in, will soon render the copper brittle.

It is a great error of young experimentalists

to be saving in the use of mercury in amalgamating the zinc plates. They cannot be too effectively done, and no mercury need be wasted; for it drops off the zinc as the latter is dissolved away, and may be collected from the bottom of the cells. The effect of amalgamation is to coat the impurities that exist on the zinc surface, even in the very best manufactured plates. These impurities consist of minute particles of various metals, that produce little batteries, causing what is called "local action." When the latter is allowed to go on, the acid is wasted, and the power of the battery much lessened.

It is also necessary that the sulphuric acid used to excite the zinc should be free as possible from nitric acid; for amalgamation affords no prevention to this acid if present. Hence, in using any form of nitric acid battery, the zinc becomes rapidly acted on, much more so than when Smee's battery is employed; because, in the former case, the nitric acid passes through the porous pots, and attacks the zinc. In a similar manner, the copper solution in Daniell's battery will gradually pass through, and cause a deposit of copper on the zinc plate if its acid solution be not frequently changed.

In making the conductors for a powerful battery, it is better to use copper strips than even stout copper wires. These strips are made by cutting up a stout sheet of copper into lengths of four feet, having a width of about an inch. They can be soldered end to end, and, at the table of the experimenter, may be finished by means of wires soldered to them, for the sake of convenient handling. It must be remembered that long, thin conductors impede the passage of the current; therefore they should, at all times, be as short and as stout as is consistent with convenient manipulation.

Returning to the question of clean surfaces and connections, we may state that a battery, in the best condition in other respects, will afford little or no results if these precautions be not carefully attended to. On one occasion we had fifty large-size carbon cells prepared for a lecture, with the best of acids, &c. They would scarcely afford a spark, although they should have produced an electric light at least equal to a thousand wax candles. On examining into the cause, it was found that one of the connections was not screwed up tight, and that another was covered with oxide. Thus, through the faulty condition of these two cells, the remaining forty-eight were rendered useless. This is but one out of many instances of the same cause that have come under our notice. We were much struck with the cautiousness and care of Faraday in this respect. He required but five cells of a small Grove's battery; and, to save him the trouble of having it carried a distance from the Royal Institution, we offered him the use, out of 100 pairs, of any he chose. With much politeness he declined the offer; adding that he never used any apparatus that he had not first tested, or that had not been prepared by his highly-valued assistant, Mr. Anderson, to whose great and assiduous care, in this respect, Faraday frequently gave public and private testimony.

In using a voltaic battery of many cells in single series, as already hinted, there is a tendency of the battery, when in good action, of the middle cells getting exceedingly hot, and of the acids being all boiled away. On one occasion, using sixty pairs of Grove's battery, we found two in the middle not only dry, but that the platina of one was red-hot. This should be carefully guarded against by watching the middle cells, and adding more of the acids as required.

In using a powerful battery, the conducting wires should be shielded with some non-conducting material, or it is more than probable that the operator may receive a shock that may either disconcert him or his apparatus. Nothing is better than a little thick brown paper tied over the wires, at the part they have to be held in the hand. Gutta-percha and india-rubber are apt to melt, especially if the experiments are connected with the heating and luminous effects of the voltaic current.

As the phenomena of this form of electrical development are of the most beautiful and brilliant kind, and as many of our readers will be desirous of repeating the experiments, &c., that will be detailed, we may here state that, by attending to the instructions already given, and that will be given hereafter, a little ingenuity and skill will enable them to produce, at little expense, all, or nearly all, the effects we shall point out. In our early days, the expense of electrical apparatus was so great, that few could follow the various branches of the science experimentally; but we found that, at an extremely moderate cost, the necessary instruments, batteries, &c., could be made in a manner quite sufficient for the purposes of the student. A mahogany exterior does not make a philosophical instrument a bit the better; and as all parts of voltaic apparatus may be bought for a very moderate sum, any one who will take the trouble may put them together in a manner that shall be quite effective. If the audience in a lecture-room, admiring the handsome instruments on the table, were to adjourn to the laboratory, they would be astounded to find, except in very refined branches of research, the simple contrivances there employed. Faraday made one of his greatest discoveries with a piece of apparatus, constructed by himself, that did not cost eightpence; yet on that eight pennyworth of wire much of his present fame was at first founded.

CHAPTER VIII.

THE CALORIFIC, LUMINOUS, AND OTHER PHENOMENA OF VOLTAIC ELECTRICITY.

IT has already been stated, that no branch of experimental philosophy affords such brilliant results as voltaic electricity; hence, it has been a popular subject for the lecture-table, and has, consequently, commended itself, as a matter of study, to thousands out of the pale of scientific circles. The improvements that have been made in the construction of voltaic batteries, and the cheap rate at which such may be purchased, have also tended to make its pursuit popular.

Amongst all the wonders of science, no matter what branch we take, it seems the most marvellous to obtain, from a few pots containing cold acid water, and each two metals, power of heat and light greater, by a vast amount, than any other that man can command, and only equalled by the similar effects of the concentrated rays of the sun. Many years ago, the calorific effects of a carefully-constructed lens, or a reflector, excited the astonishment of philosophers when the solar rays were so directed that the most refractory substances were melted, and, in many cases, dissipated in vapour. But now, forty or fifty cells of Grove's battery (see *ante*, p. 231), literally cast, by the heat and light power they afford, such results in the shade; for in the laboratory, the electric force developed by such an arrangement, can melt and dissipate any substance submitted to its agency if conducting the current of the battery.

We have thought it best to draw attention to some of the most striking effects of voltaic electricity before entering into the discussion of its theories and laws, because a great number of our readers may require the enticement to the study of the science that its experimental illustration so amply affords. By thus presenting its attractive features to the eye, we hope more easily to induce a subsequent deeper study by many who may peruse our pages. We commence, therefore, with the—

Calorific Effects of the Voltaic Current.—When treating on the various effects of frictional electricity, we pointed out that *resistance* in conductors chiefly led to the exhibition of all such phenomena. It is evident, that if a body be sufficiently conductive of a force, whether of heat or electricity, it cannot be mechanically affected by it; for the effects of heat, or of electricity, on any body, are just proportionate to the amount of force exercised, and the conducting power of the body. Thus our daily experience proves that an ordinary fire cannot afford heat sufficient to melt the iron grate in which it burns; for the latter carries off or conducts away the heat too rapidly to permit of such a result. But if the fuel be enclosed in a furnace made of non-conducting materials, such as fire-clay, then its force or power being concentrated, the fusion of the cast-iron is readily effected; for the latter cannot conduct away the heat thus directed on it. In precisely the same way, we have already seen, that when a bell-wire is the medium for the passage of a small amount of electric discharge (see *ante*, p. 202), it undergoes no apparent change. It freely conducts the charge, and so remains uninjured. But if that charge be too great for the conducting capacity of the wire, the latter then undergoes destruction, either by melting or by mechanical disruption (see *ante*, p. 203).

Now, precisely the same law governs the effects of the voltaic discharge. If the current have greater quantity than a conducting wire, intervening in its passage, can convey, then the metal undergoes the effects of the evolution of heat, and is easily melted into globules.

On a moderate scale, six cells, either of Smee's, Grove's, Bunsen's, or Callan's batteries, or ten of Daniell's constant battery—all described in the preceding chapter—will be sufficient to study the calorific effects of the voltaic current on metallic wires. If Smee's arrangement be used, then the silver plate of each cell should expose a surface, immersed in the liquid, of not less than about fifty square inches —or say, a plate measuring 6 × 4 inches, and being opposed on either side by an equal surface of zinc (see *ante*, p. 234). If any nitric acid battery be used (see *ante*, p. 231, *et seq.*), a much smaller surface of the negative metal will answer as well. Six cells of Grove's battery, with the platina in each cell exposing six square inches of surface immersed in the nitric acid, will afford quite sufficient quantity for the purpose; and it may be constructed for 10*s*.

The calorific effects of the voltaic current depending entirely on the *quantity* of electricity set free, the student must bear in mind, that we have already stated that the quantity depends on two causes—namely, the size of the negative plate (copper, silver, platina, carbon, or cast-iron), and the strength of the acid charge next to the zinc; but if nitric acid batteries be used, the strength of that acid equally influences the result.

For example, if six cells of Smee's batteries, with the silver plate exposing forty-eight or fifty square inches each, be charged with salt and water, the calorific effect will be imperceptible, unless under the most favourable circumstances. On the other hand, we have heated a considerable length of platina foil by using a Grove's

battery, each platina of which exposed fifty square inches of surface; but only charged with New River water. The electrometive force of the platina far exceeds that of silver, and that of silver exceeds that of copper. If, however, the six cells of Smee's battery be charged by a liquid composed of one of strong sulphuric acid to eight of water, then a length of six or eight inches of fine steel wire may be melted with the most perfect ease. The larger the plates, and the stronger the charge of acid, the thicker may be the wire to be melted.

Much misapprehension occurs with the beginner in respect to the *number* of cells required to fuse a certain length or thickness of wire. It is usual, at the lecture-table, to employ thirty or forty cells of Grove's, or any other nitric acid battery; and it may be supposed that this number is required equally for melting wires as for showing the phenomena of the disruptive discharge, or the various forms of electric light hereafter to be noticed. But this is an error. A *single* pair of plates, of very great size, will readily melt several feet of wire. If, for example, a powerful nitric acid battery be so arranged that all the negative and all the positive plates are respectively connected so that the whole battery shall form but *one* pair of plates, the calorific effects will be very great; although the chemical, disruptive, and physiological will be *nil*, or nearly so. It must be borne in mind, however, that quantity is an element of the chemical decomposing power of the current; but this is only here mentioned to prevent misconception, as it is apart from our present subject.

The conducting wires being properly affixed to the terminal plates of the battery (and these wires should be not less, in any case, than No. 16 gauge copper for a small arrangement, and be much thicker—say 10 gauge, for a large battery), on being connected by means of a fine steel wire, will, if the latter be sufficiently thin, at once melt it into globules; and care should be taken to prevent their falling on any combustible substance, by strewing a little sand on the table at which the experiments are carried on. The inferior conducting power of the thin wire, and the consequent destruction of it by melting, may be illustrated by making a longitudinal chain of alternate links of the fine steel and coarse copper wire. On connecting this with the terminal wires of the battery, the fine wire will instantly melt, whilst the thick copper will remain unaffected. This experiment may be conducted in the manner illustrated in the following cut, in which the thick wires are represented as fixed to a table or stand, in such a manner that they may be joined alternately by fine steel wire. On the current being sent through, the latter will be melted.

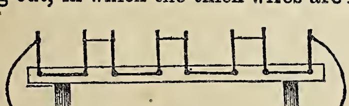


Fig. 147.

Although we have stated that a *single pair* of plates, of large size, will melt a considerable length of wire, still, in practice, a number of plates of large size is generally used. This is so done because the number, by increasing the intensity, assists the quantity to overcome the obstacles of the length of the conductors in the conducting wires. It is true that a stout metal wire is a good conductor; but the practical electrician finds, that in using various kinds of copper wire, some will resist the current to a greater extent than others. If the copper be pure, then the conducting power is greatly increased.

From this fact we can here explain how it is that a current which will easily melt a wire of iron or steel, shall leave another of copper or silver unheated, presuming that each wire has an equal sectional area or diameter. The fact is, that the copper and silver are far better conductors than the iron; or, in other words, an iron wire, having the same sectional area, affords greater resistance to the passage of the current, and, consequently, undergoes melting.

If a wire be chosen so that it shall become moderately red-hot in the open air, and it be afterwards enclosed in a glass tube, and its ends be again connected with the battery, it will attain a much higher temperature in the tube. This is due to the fact, that the carrying away of heat by uprising currents of air, or *convection* (see *ante*, p. 189), is prevented. And if, in place of putting the wire into the tube, stretched in a line, it be coiled up over a piece of wooden rod so as to make it into a helix, like the spring of the ordinary house-bell, the amount of heat produced, and the actual length of wire heated, will both be largely increased, because each adjacent side of the helix tends to maintain its neighbour at a high temperature; consequently, by such an arrangement the heating effects of a small battery may be made much more powerful.

If a battery in strong action be attached, by its terminal wires, to such a coil of fine wire, and the latter be immersed below the surface of water, in a glass or porcelain vessel, the liquid will speedily acquire a sufficiently high temperature to convert it all into vapour.

In trying this experiment, a singular result may possibly occur; that is, the fusion of the extremities of the fine coil between the water and the terminals of the conducting wires: but this phenomenon is best observed as follows:—Take such a length and thickness of wire that it shall become only red-hot by the passage of the current through it in air. Now bend it so that its middle shall dip into a vessel of cold water, leaving, above the surface, an interval between the water and the conducting wires of the battery. It will be seen that the wires on either side will become much hotter than when the entire wire is extended in the air; and by diminishing the length of wire in the air on either side, by immersing the central portion more in water, the extremes will, most probably, be melted.

The explanation of this is simple. By cooling

the central portion of the wire in the water, it is rendered a better conductor than such portions as are allowed to remain in the air. The whole force of the current is, consequently, thrown on the two extremities. As they get hotter they conduct worse, increase the resistance to the passage of the current, and, consequently, become melted.

One of the most magnificent spectacles presented even by voltaic electricity, is that resulting from heating a length of magnesium wire by the voltaic current. On becoming a little beyond a bright red heat, the wire melts, and, instantly taking fire, burns with the most beautiful coruscations of blue-white light. Next to this is the combustion of steel wire, which scintillates very brilliantly.

By a modification of the preceding experiments, the phenomena and effects of resistance, in producing heat by means of a good conductor, imperfectly in contact in its parts, may be shown. For this purpose it is desirable to use about thirty cells of a nitric acid battery, of any kind, in good action. A basin should be partly filled with *clean* iron filings; because, if only partially oxidised, the effect is greatly diminished. The two terminals of the battery conducting wires are then to be immersed in the iron filings, at a few inches distance from each other. After a few seconds, the iron filings will become hot, and gradually the mass between the conducting wires will so increase in temperature as to acquire a red heat. In some parts they will actually fuse, and, consequently, become a solid mass when cold.

The imperfect contiguity of the particles or grains of the filings, offers resistance to the passage of the current; and, therefore, a large mass of iron may be so heated, much exceeding in weight that which would be heated to a similar extent in the form of wire. But if brass or copper filings be substituted for the iron filings in repeating this experiment, no such result as the above will accrue, their superior conducting power causing them to afford less resistance to the current; and, consequently, preventing the evolution of any considerable amount of heat.

The application of the calorific effects of voltaic electricity for the purpose of igniting charges or blasts of gunpowder, gun-cotton, &c., in mining, engineering, marine torpedoes, &c., &c., is familiar as having been largely employed both in the arts of peace and war for such purposes. In such cases, two long conducting wires, insulated from each other, extend from the charge to any convenient situation for the battery. *Inside* the charge, although separated to the distance of an inch, they are connected by means of a fine steel or platina wire, the end of the latter being twisted around each conductor, and forming a loop that rests in the powder. On the further extremities being connected with a voltaic battery, the current passes, and ignites the charge at the other extremities of the conducting wires. Voltaic electricity, and electricity induced by its agency or magnetism, are the only feasible methods of igniting torpedoes for naval purposes, as they alone permit of a choice of the moment at which the explosion should be effected; and as, for all practical purposes, the effect is instantaneous on sending the current, the result, if proper precautions in other respects be taken, can be completely relied on.

It is a singular fact, that although the value of a voltaic current has been so many years known, in respect to igniting powder at any moderate distance, in our country, at least, it is rarely, if ever, employed by the miners; only being adopted by the scientific engineer. This curious fact is easily accounted for, however. The perfect safety of the voltaic method entirely does away with any danger of an explosion taking place in a charge, as too commonly occurs when the fuse is employed. But the removal of this source of danger at the time, lessens the risk that enhances the wages of the miner, and, consequently, the latter invariably prefers the chance of death to himself and comrades, to safety and a possible trifling reduction of wages. In many other dangerous branches of trade, where science has brought forth a remedy or preventive, precisely the same perversity is displayed. It is well known, for example, that a coal miner will not hesitate to jeopardise the lives of hundreds by unlocking his Davy to light his pipe: at home he keeps his gunpowder beneath his bed for the sake of safety! But we need not adduce more to show how apparent self-interest too frequently over-rides the demands of duty.

The *Luminous effects* of the voltaic current far transcend those already described; but they are nearly related, because the production of light by the current is always attended by that of heat.

It must be borne in mind, however, that whilst the luminous effects of voltaic electricity apparently resemble those of combustion, it is not the latter circumstance that is the effective cause, for the phenomena take place almost with equal brilliancy in the absence of those conditions that are essential to perfect combustion. At the same time there is a great analogy between the effects of the disruptive discharge of voltaic electricity and those evidenced in combustion or ignition. In either case it is essential that solid matter should be present in a volatilised form

For example, if a jet of hydrogen gas be ignited, as produced from the decomposition of water, by pouring dilute sulphuric acid on a few zinc or iron nails, the flame produced has the most trifling luminosity. But if, to the liquid in the vessel producing the gas, we add any highly carbonous liquid, such as sulphuric ether, camphine, benzole, or the like, an amount of carbon is furnished that affords the necessary solid matter, and complete luminosity is the result. So with the voltaic disruptive discharge, by the transference of solid matter between the two terminals of the conducting wires of the battery, the effects of heat and light arise, or are due.

By the term "disruptive discharge," we mean

that effect which takes place when the terminals of a powerful battery are brought first into contact, and then separated. Take, for example, that which occurs when the conducting wires are tipped each with a piece of boxwood charcoal, or the carbon obtained from the inside of a gas retort, already mentioned at p. 232, *ante*, as a fit material for a negative plate in Bunsen's battery. In the following cut the primary effect

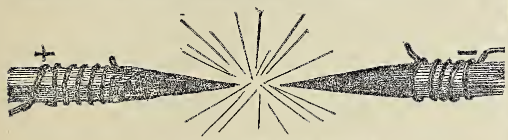


Fig. 148.—Voltaic Spark.

is illustrated. If the battery be small, a bright spark occurs, and the sharp points of the charcoal become brilliantly illuminated.

If, however, the battery be of considerable size, then the phenomenon produced is of the most brilliant character. The charcoal points, after coming in contact, may be separated to the

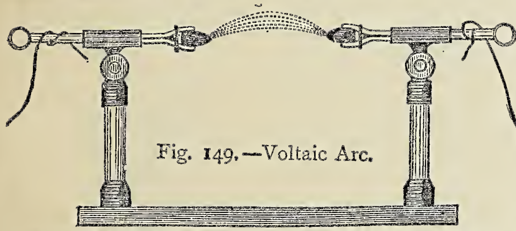


Fig. 149.—Voltaic Arc.

extent of an inch, or more; and between them, as represented in the above cut, an arc of flame, of dazzling splendour, will pass. Its diameter, or depth, depends on the size of the plates employed; whilst its length, presuming that the negative plates are of sufficient size, depends on their number. Thus, if a platina battery, of Grove's arrangement, be used, each platina exposing an effective surface of twenty-five square inches, with double-facing zincs in the flat-cell form, an arc of flame, about an inch and a-half between the two points, may be kept up. One hundred cells of the same size will afford an arc about three inches long.

The result here alluded to is that popularly known as the electric light. It is produced by the transference of minute portions of the carbon of the points from one pole to the other. That which terminates the *negative* plates of the battery (say platina, carbon, silver, or copper), loses carbon; whilst that which is connected with the zinc plate of the battery, gathers carbon from the opposite terminal, and thus, within certain limits, the disruptive discharge of the voltaic battery is analogous to the chemical effects.

We have experimented, lectured, and written, *ad nauseam*, in respect to the availability of the electric light for illuminating purposes, as that light is derived by the current of the voltaic battery As obtained from that source, it has hitherto been simply a failure for all practical purposes; and, after experimenting with the most powerful voltaic batteries, we are compelled to assert our decided conviction, that, so far as our present means of obtaining light by the voltaic current is concerned, there is not the most remote chance of turning the light to any practical purposes, if economy and convenience are to be consulted. It must be understood that these observations are strictly confined to the results obtained solely by the voltaic battery. A voltaic battery, to be effective, requires the attention of a person well versed in the science; and even such an individual will, at times, find his resources severely taxed. Formerly connected with institutions where no expense was spared to render a lecture effective, and having personally had constructed voltaic batteries of the highest power, we can only say that, except for such exceptional cases as an illumination, lighting up a course or battle-field, or some such similar extraordinary matter, the electric light, as produced by the voltaic current, is purely useless.

For reasons above stated, all hopes of applying the electric light generally for illuminating purposes had been abandoned. But by successive improvements, the electricity as induced by magnetism, has overcome nearly every difficulty. The magneto-machine in the days of Faraday was simply a curiosity. But now it has almost become a necessity to us. In 1875 some portions of Paris during the Exhibition were illuminated by the electric light as produced by that machine. This gave a stimulus to invention. A host of machines and lamps were invented. In England and the United States, various improvements were made, and suffice to say for the present that so great was the progress made, that in 1881, the bridges, chief streets, and public buildings, factories, shops, etc., in London and many provincial towns, were thus lit up. This subject will be amply dealt with and illustrated in a future Chapter, in which we shall also include some other subjects, such as the storage of electricity, its application as a motive power, the application of the electric light to horticulture, and numerous other interesting subjects.

We next turn to relate some of the effects of the disruptive discharge, as afforded by metal terminals; and these are amongst the most beautiful of all electrical phenomena, whether we regard colour or brilliancy.

Each metal is distinguished by the colour it affords in the voltaic disruptive discharge. If a small battery be employed—say from six to ten cells of Smee's, or a few of any kind of nitric acid batteries—an arrangement like the following is useful to show the deflagration of the metals, and the peculiarity which each presents. *a* is a polished metallic plate, connected by a wire, *b*, with one end of the battery; *c* is the other wire of the battery, at the end of which is some metal leaf, *d*, as of platina, gold, silver, copper, and zinc. On bringing *d* into contact with the surface of *a*, the deflagration at once takes place. Gold gives a bluish-white light; silver, a rich dead-green; copper, a brilliant green; lead, a purple; zinc, a rich blue, fringed with red; magnesium, a fine bluish-

white: and so each metal has its characteristic disruptive discharge.

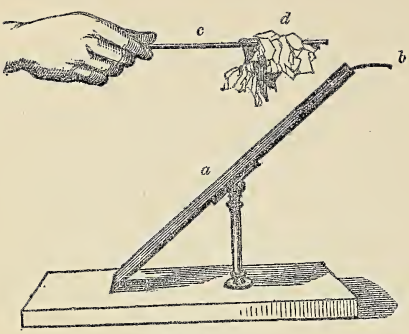


Fig. 150.

When, however, a powerful battery is employed, such as forty or fifty cells of a nitric acid battery, exposing about twenty-five square inches of either platina, carbon, or cast-iron in each cell, the effects are of the most splendid kind. In using such a battery for this purpose, it will be convenient also to employ the apparatus illustrated at p. 239, Fig. 149, *ante*, substituting points of the metal for those of charcoal there illustrated. The effects of monochromatic light, or that which sheds but a single colour on surrounding objects, are seen to the highest advantage. The arc of flame, when metal points are employed, is always shorter than when produced by charcoal points; but the results are equally brilliant. Thus, if a pair of copper or silver points be employed, all surrounding objects appear of a pale-green colour, especially evidenced by the faces of lookers-on, who exhibit a ghastly appearance.

The effect on the eyes of the experimenter is remarkable. If the eye be not more than one or two feet from the light, and unshaded, after a few seconds all appearance of the disruptive discharge is lost; a kind of paralysis of the optic nerve results. When charcoal terminals are used, the effect is still more singular; for whilst persons at a distance from the light find it too dazzling to behold, the operator merely perceives a red-hot state of the charcoal, and becomes quite insensible to the powerful luminous effects before him. When, however, the light is extinguished, the operator is incapable of distinguishing any object for some time; a kind of halo of light and darkness affects him, that renders it impossible to exercise the power of distinct vision for some time afterwards. Presuming that the experiment had been tried with not less than fifty large cells of any nitric acid battery during the evening, on the recurrence of daylight, the inflammation of the eye is severe, and the pain at viewing even the subdued light of the sun is excruciating—indeed, at times, maddening; the intensity of the effect depending on the sensitive condition of the organs of sight in the individual. A remarkable instance of this occurred some years ago, within our own knowledge; and we have, to a less degree, experienced the same effects. A friend had experimented with fifty cells of Grove's platina battery in good action, the platinas each exposing twenty-five square inches of active surface. On the following morning we were hastily called up at an early hour, and witnessed the result of the action of the intense light of the charcoal disruptive discharge in a strong inflammation of the face of our friend, accompanied with an intolerable pain of the eyes on the least exposure to light of day. These facts may act as a warning to those who have the means of experimenting with a powerful battery, in relation to the disruptive discharge; for in all such experiments the eyes should be protected by dark glasses.

One of the finest effects produced by the disruptive discharge, if a powerful battery be employed, is that of the deflagration of steel watch-spring, a small file, or the large blade of a penknife over mercury. The wire from the platina or carbon end of a powerful nitric acid battery in strong action, should be immersed in a glass vessel containing mercury, whilst, at the end of the wire proceeding from the zinc end of the battery, either a piece of stout watch-spring, the file, or knife should be attached. The latter is first brought into contact with the mercury, and then withdrawn to the extent of a half inch or an inch from the mercury, according to the strength of the battery, as illustrated in the annexed cut. The most magnificent effects are produced; frequently the melted steel will burst forth, volcano-like, to the height of several feet, with the most brilliant coruscations, affording, perhaps, the finest spectacle that experimental science or any art of man can produce.

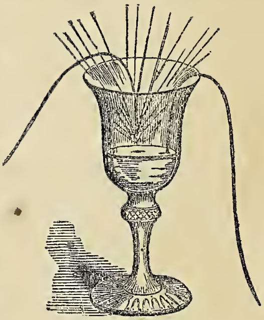


Fig. 151.

The disruptive discharge between magnesium points is also of great beauty. The moment the two points of magnesium get into contact, a dazzling effect is produced, if the battery employed be powerful, and in good working order. Intense combustion of the metal ensues; one, at least, of the bars will become white-hot, and melt; and if it be then plunged into water, the intense heat will decompose that fluid, portions of the burning metal rushing over its surface in a state of combustion, much in the same manner as may be seen on throwing a piece of potassium on water, only that the effects are infinitely more brilliant. Hydrogen is simultaneously liberated, and burns on the surface of the water.

In applying the voltaic battery to the purposes of artificial illumination, amongst many other experimenters, mention should be made of Mr. Hearder, of Plymouth, who has attained considerable eminence in that branch of the applications of electricity. We have not space to afford for transcribing an account of his experi-

ments in 1862, and subsequent years, for testing the value of the electric light for the purposes of warfare. Suffice it to say, that, under such circumstances, and for lighthouse illumination, where expense can be no object, the electric light, especially as produced by Holmes' magnetic machine, is invaluable. All forms of disruptive discharge produced by electricity have an enormously penetrative power. By this we mean, that whilst the ordinary oil or gas-lamp—say in the lighthouse lamp—would, in a hazy night, not be visible a mile off, any form of the electric disruptive discharge would be seen at a distance of several miles. Under such circumstances, also, the electric light forms a remarkable cone of rays, that, comet-like, streams overhead, and is altogether peculiar to it. The lengthened and successful use of Holmes' light at Dungeness and the Foreland, has, at least, pointed out one of its important applications; but as the method of producing the light is not by means of the voltaic battery, we must defer this subject for consideration to a future chapter.

Having thus stated some of the most interesting facts in connection with the calorific and luminous effects of the voltaic current, and continuing, for the present, only an elementary view of the subject, we next turn to the exposition of some of the leading facts connected with the *chemical effects* of voltaic electricity, instancing, for the present, only such as will tend to give an insight into this interesting and highly important subject.

If the ends of the conducting wires, from a battery of six cells, either of Smee, Grove, or the carbon arrangements, be affixed to a narrow strip of platina foil, so that the latter may form the poles, terminals, or *electrodes** of the wires; and if these platina electrodes be immersed in a little dilute sulphuric acid and water, a torrent of minute bubbles of gas will be given off from each. The reason platina should be used is, that it undergoes no action on itself by this experiment.

On collecting the gases separately, it will be found that one of them consists of pure hydrogen, which may be ignited as it reaches the surface of the liquid; whilst the other is pure oxygen, the presence of which may be detected by bringing a smouldering match in contact with the gas, when the match will glow with an increase of light, and will probably be re-ignited.

The interesting discovery of the decomposition of water by voltaic electricity, was first made by Nicholson and Sir Anthony Carlisle, about the year 1800; but the battery they employed, at first produced, from its weakness, but trifling effects. Eventually, however, by improved arrangements, they succeeded in showing that the voltaic instrument had sufficient power to decompose water.

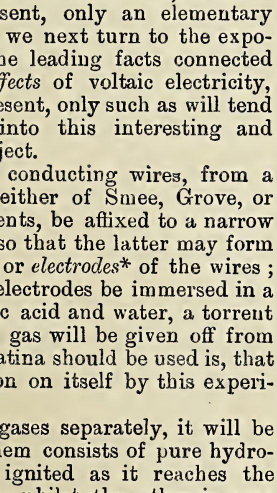


Fig. 152.

A variety of instruments for the purpose of showing this fact, collecting and measuring the gases evolved, have been invented. In the preceding cut one is shown, by which the mixed gases are collected together. *a b* are two mercury cups, in which the terminal wires of the battery are inserted. From these cups run two wires, ending in two platina plates, placed vertically at the bottom of a tube, *c*, in a vessel, *d*, containing acidulated water. The tube, *c*, is first filled with acidulated water; and whilst still full, inverted in that of the vessel, *d*, over the platina plates. The moment the battery wires are connected with *a* and *b*, electro-chemical decomposition of the water ensues; bubbles of gas rise into the tube, and, at last, fill it. When full of the gas, if it be presented to flame, an explosion ensues, and water is re-formed.

In the following cut another apparatus is represented, by means of which the two gases may be obtained separately. It is, in all respects, similar to the precedingly described apparatus, except that two tubes are provided in place of one. It will be noticed, that, in the engraving, the left-hand tube has the water much more depressed than the right-hand tube; and this indicates that about twice as much in *bulk* of hydrogen is given off by the decomposition of water by voltaic electricity, than is afforded of oxygen. But this does not affect the weight, for one grain of hydrogen is produced for every eight grains of oxygen; so that the law of chemical combination, already referred to at p. 226, is equally true in respect to the action both in and outside of the battery.

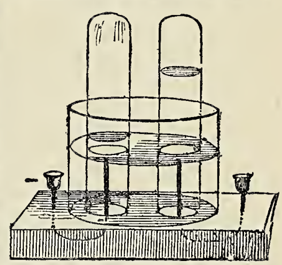


Fig. 153.

When the two tubes are filled they may be successively tested as follows:—Remove that containing hydrogen with its mouth *downwards*; because, being lighter by much than the air, the gas would instantly escape if the tube were held with its mouth upwards. On applying a light the gas will at once catch fire. The tube containing the oxygen, when filled, should, on the contrary, be treated differently, because oxygen is heavier than atmospheric air. The finger should, therefore, be placed over the open end of the tube before it is removed from the acid water. The tube is then to be inverted, so that its open end shall be uppermost, when the greater specific gravity of the oxygen will, for some time, prevent its admixture with the air. On immersing a smouldering match with a red-hot end, but without flame, the match will at once re-ignite with an almost explosive noise, showing that oxygen gas is, without doubt, present.

When the gases are required for purposes in

* From the Greek, signifying a *way* or *road* for the passage of electricity.

quantity, another arrangement is employed, as represented in the following cut. The platina

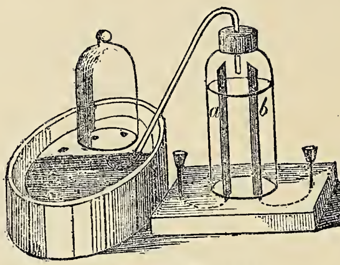


Fig. 154.

plates, *a b*, are enclosed in a jar containing acidulated water. From the top of the jar is carried a bent tube, the lower open end of which is placed below a vessel filled with water, and resting on the tray of a pneumatic trough; by such means an unlimited quantity of the mixed gases may be obtained, for the production of the lime-light, or any other purpose.

During the decomposition of water by the voltaic battery, as also during the working of an electrical machine, a peculiar odour, somewhat resembling that of phosphorus, is perceived. It is due to the production of what is called *ozone*, the nature of which has yet to be learned; but its presence, in a free state, may often be recognised in fresh air, but especially after a thunder-storm. We cannot here enter into any description of what is known of ozone, as such would more particularly belong to the sciences of chemistry and meteorology; and, therefore, only bring the simple fact of this mode of its production before the reader's notice.

We must next draw attention to certain laws that are discovered as ruling the decomposition of water, and the separate evolution of gas at the respective poles.

At Fig. 153, *ante*, it will be seen that the left-hand tube contains, as previously stated, hydrogen. That it should be so filled, the platina plate, or electrode, from which it is evolved, must be connected with the zinc terminal, or *positive* plate, of the battery, when, of course, the platina plate in the tube becomes the negative pole, or electrode, and is, consequently, marked *minus*, or —, in the cut. On the other hand, to evolve oxygen, the platina plate affording it must be connected with the negative, or copper, silver, platina, carbon, or cast-iron plates of the battery, according to which kind is used; and, consequently, the plate evolving the oxygen will be positive, or plus, +, as marked in the cut. This distinction has already been pointed out at p. 227, *ante*, when we described the decomposition of the solution of sulphate of copper, for the purpose of showing that metallic contact is not absolutely necessary to produce the effects of the voltaic current, and that chemical action alone is necessary.

A vast variety of terms have been used to designate the ends of wires, plates, &c., employed in electro-chemical decomposition; but, with the exception of the term electrode, we have only noticed those of "poles," formerly employed. The use of the latter involves theoretical ideas, the truth of which has been challenged; and Faraday, consequently, suggested others, that have no theoretical signification, but merely express the apparent office or connection of each. That terminal, or pole, ending the wire proceeding from the negative plate of the battery, he denominated the *platinode*, or *anode*; whilst that ending the wire proceeding from the zinc end or plate of the battery, he called the *zincode*, or *cathode*. The anode is, therefore, under the supposition of the passage of current, that way or road by which the electricity *enters* a decomposing solution; and the cathode, that way or road by which the current leaves that solution. These terms have been extensively adopted by electricians, in place of positive and negative, than which they are more definite and convenient.

When describing the chemical effects of frictional electricity, at p. 205, *ante*, it was stated that, whilst it was essential to have only pure water for exhibiting them in the decomposition of that fluid, with the voltaic current, it was necessary to improve the conducting power of the liquid, so that abundant decomposition may take place. It must here be noted, that, after a certain amount of intensity has been gained, an increase in the *number* of plates only triflingly increases the amount of gases afforded by the voltameter, as the preceding instrument is called. Thus if five cells of Grove's platina battery be employed, they will afford—say, for example's sake, 5 cubic inches of the mixed gases per minute. If ten were used, the amount of gas would only be raised—say to about $6\frac{1}{2}$ to 7 cubic inches. But if five cells, exposing double the surface of platina in each to that first employed, were used, then the amount of gas produced would be doubled, or amount to 10 cubic inches per minute, or thereabouts.

Each kind of battery requires a certain number of cells to overcome the resistance of the water. Ten or twelve of Daniell's, the same number of Smee's, and four or five of any nitric acid battery, give about an equal amount of intensity for such a purpose; and beyond that number an increase is of no avail. But by increasing the size of plates after that number, the product in cubic inches is generally increased in equal proportions. As an instance of this, we may mention that, being desirous of producing the mixed gases in abundance direct from water, for the purpose of the lime-light in a dissolving-view apparatus, and oxy-hydrogen microscope, we arranged a battery of fifty cells of Grove's, so that it formed five pairs only, each ten pair being united to form but a single plate, in the manner already described at p. 234, *ante*. By this arrangement we obtained nearly 100 cubic inches of the mixed gases per minute; whereas, by the same battery arranged as fifty cells, only about 20 cubic inches were produced. This is a subject, however, that may possibly be again referred to, as explanatory and illustrative of some of the laws of quantity and

intensity, in regard to the action of any form of voltaic battery.

In constructing any form of voltameter, as illustrated by Fig. 152, p. 241, *ante*, it is as important that the platina electrodes should be as close together as possible, as we have shown it to be in constructing a voltaic battery. The further the plates are apart, the greater is the distance the current has to travel, and, of course, the larger is the resistance to its decomposing effects.

We next turn to illustrate some of the results arising from the action of the voltaic current on saline solutions; for the present merely stating facts, and reserving the discussion of electro-chemical theories for another place.

If two electrodes of platina be immersed in a solution of sulphate of soda, and the vessel containing it be divided by a porous diaphragm, the whole contents being coloured by a little tincture or solution of litmus, and the action of a battery of two or three cells be employed according to the manner suggested in the following cut, decomposition of the salt will at once

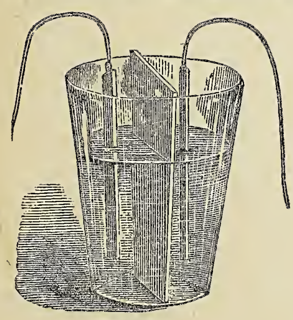


Fig. 155.

ensue. After a short time, one side of the vessel will have all the blue-coloured liquid turned red; whilst the other side will retain its original colour. It is evident, therefore, that the sulphuric acid of the sulphate of soda and the latter alkali have been separated; in other words, that the saline solution must have undergone decomposition. It will be found that the soda is apparently retained at that side in which the cathode or zincode is immersed; whilst the department of the vessel holding the platinode or anode, presents free acid. If a solution of common table-salt (chloride of sodium) be employed in place of the sulphate of soda, and the solution be coloured by litmus, the anode side of the liquid will become bleached, through the liberation of chlorine; whilst the other, or cathode side, will retain its blue colour. Again, if iodide of potassium be used, and the solution be mixed with a little cold starch, the anode or platinode department will be coloured blue, through the liberation of free iodine, which has that power on starch; whilst the cathode or zincode side will retain its white colour.

From the preceding experiments, we thus find that, under certain circumstances, oxygen, oxygen acids, chlorine, and iodine, invariably, under the circumstances related, appear free at the anode; whilst the base soda, or oxide of the metal sodium, or potass, the oxide of the metal potassium, appear at the cathode. It hence results, that the substances set free have an opposite electric state to the poles at which they are evolved, and are set free accordingly.

On these facts Davy founded what is called an electro-chemical theory; that is, he presumed that electrical attraction in this form, and chemical affinity, were identical. The novelty of the facts, however, led him to hasty generalisation, that has had to be modified or altered by subsequent experimenters. At the same time, it must be admitted, that, even at the present day, a portion of Davy's theory is adopted; and bodies capable of chemical attraction, and decomposition, still receive the names of electro-positives and electro-negatives.

It is not necessary, in carrying out the preceding experiments, that the solution should be held in one vessel, divided by a diaphragm. Thus an apparatus, represented in the following

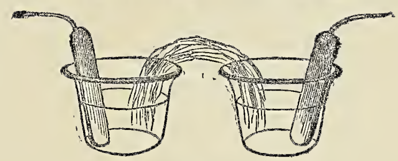


Fig. 156.

cut, may be employed. Two separate glass cups are shown, each being filled—say with a solution of sulphate of soda, coloured by litmus, and connected by means of some lamp-cotton, or pieces of amianthus, first well wetted with the solution. The moisture the fibres hold will maintain electrical communication or conduction between the two cups, provided the ends of the thread or amianthus are immersed in each cup. If now the electrodes of the battery are introduced respectively into each cup, decomposition will ensue. One cup will have its contents reddened, whilst the other will retain the blue colour. If three cups be employed, the centre one will be unaffected, whilst the two extreme ones will undergo the changes just related. By changing the position of the electrodes—that is, putting the cathode into where the anode was, and the latter in the place of the former—the changes in the liquid will be gradually reversed.

This experiment is both highly interesting and instructive. Davy carried it still further by apparently passing an acid through an alkaline solution in the middle cup, or an alkali through an acid in that vessel; hence he came to the conclusion, that "the total dual influence of the voltaic battery is concentrated in its two ends, or poles, and arriving at the conclusion that all compounds might be resolved into successive binary [that is, such a combination as consists of one element united to another—as oxygen with hydrogen in water] grouping, by exposing them to the influence of sufficiently powerful voltaic attraction." * * * "He imagined all elementary bodies, and, indeed, all substances generally capable of taking part in chemical combinations, to be endowed by

nature with one definite kind of electricity; and that two molecules, or aggregate of molecules, having opposite electrical states, being brought in contact under favourable circumstances, would combine and form a chemical compound; hence, according to him, chemical affinity is for molecules that which frictional electricity is for masses—a dual force, penetrating matter, and each function of duality mutually attractive of the other. These premises being granted, it should follow, conversely, that if electrical power, having greater strength, accomplishes chemical union of particles, the application of electrical power, having greater strength, should separate those particles: and this is the explanation, according to Davy, of what occurs when water is decomposed, oxygen being attracted to the positive pole [or anode] with a stronger attraction than that exercised by the associated hydrogen, and *vice versâ*," the latter element appearing at the cathode, or negative pole. The investigation of Faraday's discoveries, in respect to this and other theories, will prove, in part, the errors of Davy's views, and place us in possession of the real facts of the case.

We may here remark that fluidity is essential in all cases of decomposition by the voltaic current; and, moreover, many solids, reduced to the fluid condition by heat, become decomposable by the action of the current. Thus chloride of silver, which, in its solid state, is at once a non-conductor and indecomposable, on being fused is at once changed to the condition of the conductor of the voltaic current, and is also simultaneously decomposed. Conduction is, consequently, as we have already shown, a condition of chemical decomposition by voltaic agency.

Davy's reputation as a chemist was raised to its zenith when he discovered that potass and soda were simply oxides of metals, just as are iron rust, red lead, and the like. Placing a piece of moistened potass in connection with the two electrodes of a (then) powerful battery, he discovered, that if mercury were present, an amalgam was produced, that, on being cast into water, caused the evolution of hydrogen gas: it was evident, therefore, that he had succeeded in separating something which had a greater attractive power for oxygen than was possessed by hydrogen. On distilling the amalgam so produced, he discovered a metal, that, when cast into water, inflamed, owing to the decomposition of that fluid, and the evolution of hydrogen, together with the eduction of intense heat, generated by the great exercise of chemical affinity that ensued. Pursuing the same method with soda and the alkaline earths, he was enabled to show that these are simply oxides of metals, and not elementary bodies; and hence he added greatly to our means, not only of analysis, but also increased the number of the elementary substances, or those which have as yet resisted all our attempts to reduce them into simpler forms. How much soever we owe to Faraday and his contemporaries, it must be admitted, that to Nicholson, Carlisle, and Davy, is due the merit of first pointing out the chemical agencies of the voltaic current; and, further, any one perusing the *Bakerian Lectures* of Davy, and the *Experimental Researches in Electricity*, by Faraday, cannot help perceiving that the latter became a successful philosopher through adopting the careful experimental habits of Davy.

Nearly every case of electro-chemical decomposition, or electrolysation, that we have adduced, has been that of binary compounds; and, as we shall hereafter see, it is only these, or such as partake of their nature, that are capable of *direct* decomposition by the voltaic current. We have already, in part, stated the nature of a *binary* compound; it will be here, perhaps, well that we should more explicitly state what is meant by the term.

Water and common salt, for example, are binary compounds; as is also the chloride of silver. Each of these consist of *only two* elements; hence the term binary, from *bis*, *two*, or *twice*. Water is composed only of oxygen and hydrogen; common salt, of chlorine and the metal sodium; chloride of silver, of chlorine and silver. Hence, when these are submitted to the chemical action of the voltaic current, they are completely decomposed, the oxygen and chlorine appearing at one electrode, the anode or platinode, and the hydrogen, or the metal (or oxide), at the cathode, or zincode. In the case of the decomposition of the sulphate of soda, the sulphuric acid acted or suffered like the oxygen or chlorine, and appeared at the anode; whilst the soda (oxide of sodium) appeared at the cathode like a metal. Hence, for the present, we may consider, for the sake of simplicity, that sulphate of soda is a quasi-binary compound in relation to the action of the voltaic current.

This leads us to a fuller explanation of *secondary action*, previously alluded to, when we described the construction, management, &c., of Daniell's constant battery, at p. 229, *ante*.

In the decomposition of a binary compound, such as water, one element invariably appears at one electrode, and the other at that opposite, in electrical character. But, in secondary action, two elements are presented at one of the electrodes. Thus, if, in place of immersing the two platina electrodes of a battery in acidulated water, they are introduced into some metallic solutions, the cathode will evolve hydrogen; but this will be imperceptible, because, at the very instant the evolution takes place, the oxide of the metal, as in a solution of sulphate of copper, is decomposed, water being formed, and the copper being precipitated. If, as just stated, two platina electrodes be employed in such an experiment, the anode, or that ending the wire proceeding from the platina, copper, or negative plate of the battery, will evolve oxygen; whilst the opposite electrode, or the cathode, is receiving a deposit of copper. So soon as all the salt of copper in the electrolysed solution is decomposed, then the cathode, instead of receiving a further coating of copper (which would be obviously impossible), evolves hydrogen.

Now the secondary action is evinced in the nascent hydrogen decomposing the oxide of copper at the cathode, and precipitating the

metal on that electrode. But the secondary action at once ceases on all the copper salt becoming exhausted of its oxide. Then water becomes decomposed, and, in place of secondary action, we have the direct decomposition of a binary compound water, the only other remaining compound in the liquid being sulphuric acid, which, as explained at p. 242, *ante*, simply serves to improve the conducting power of the water, but in no case undergoes decomposition.

The effects of secondary action are, consequently, due to the energetic action of nascent hydrogen in seizing on oxygen, present also in the nascent form. In practical chemistry, apart from any known connection with electric agency, this strong affinity is taken advantage of. For instance, the oxides of metals may be frequently reduced by passing a stream of hydrogen over them at a high temperature, when no other means will produce the same result. But the nascent form—that is, the instant of evolution, or that preceding it—is most favourable for metallic reduction; and this lays at the foundation of every process in the deposition of metals by the electrotype process.

But secondary action is not confined simply to the deoxidation of metallic oxides, and the deposition of metals. At p. 233, *ante*, a diagram, Fig. 145, was given, which showed precisely the same results in regard to nitric acid, in Grove's and other nitric acid batteries. In such cases we may look on nitric acid practically, at least for our purpose, as a highly oxygenated base. That acid is composed of one equivalent of nitrogen, united with five of oxygen. In the action of the battery, the nascent hydrogen, at the negative or platina plate, at the moment of evolution, combines with a portion of the oxygen of the nitric acid, just as it does with the oxygen of the oxide of a metal, as that of copper, previously instanced. In both cases water is produced by the combination of the oxygen with the evolved hydrogen. In the case of the nitric acid decomposed in the nitric acid batteries, the results are much more complicated, for several products result. First, binoxide of nitrogen is given off, and afterwards ammonia. But the latter may be practically regarded in a similar light to that of the deposition of a metal. It is, like potass and soda, an alkali; and, moreover, is constituted of the analogues of a metal—namely, nitrogen + hydrogen. Indeed, if the present hypothetical ideas respecting ammonium be entertained, the analogy, or rather identity, is still more complete; for we have a real or quasi metal, or its oxide, evolved in a gaseous form, which does not in any way invalidate the case; for ammonia, in its pure state, is always gaseous at common temperatures, just as mercury, unlike all other metals, is fluid under all ordinary circumstances.

These illustrations, therefore, will assist the reader to understand the nature of what is called "secondary action," and the distinction that subsists between it and direct decomposition of a binary compound. Its application, in connection with the art of electrotyping, is too extensive to be here noticed. We may add, however, that, for philosophical purposes, secondary action is often used to effect decompositions that cannot be arrived at by direct decomposition by the agency of the voltaic current; so that, consequently, many compounds not decomposable directly, are made so in an indirect manner.

Attention has, hitherto, been chiefly directed to the effects produced at the cathode by secondary action, in the absorption or chemical reunion of the nascent hydrogen with oxygen. But a very beautiful and instructive result may be obtained by manipulating with the oxygen evolved at the anode, in a metallic solution, and with a metal not at the moment acted on. Thus, if a bright piece of platina foil be immersed in a dish, and covered with a solution of acetate (sugar) of lead, and attached as an anode, by a wire, to the negative plate of the battery, and a wire forming the cathode be also immersed in the solution, over, but not touching the platina—say at a distance of half an inch off—a magnificent series of rings will be formed on the platina plate, of every imaginable hue, and constituted of oxide of lead. The rapidity and distance of the production of Nobili's rings (as they are called, from having been first produced by that electrician), vary according to the distance of the cathode, and the power of the battery; three small cells of any nitric acid battery being ample for the purpose. In appearance they somewhat resemble Newton's rings, produced by compressing a lens of great focal length on a piece of flat plate-glass.

A still better method of producing the rings is, to employ a piece of highly-polished steel in place of the platina plate. For the short time that the steel is exposed to the action, it is not affected by the current. Its extremely even, smooth, and polished surface heightens the brilliancy of the result. As soon as the best effect is produced, the plate of steel should be removed from the solution of acetate of lead, and be well washed in warm distilled water; and the appearance may be retained in all its beauty by gently heating the plate, and then coating it with a thin surface of any white transparent varnish.

We do not here propose to enter into any further investigation of the laws of electro-chemistry, as they will become the subject of detailed investigation hereafter. Our present object is to present a general view of the most interesting features of voltaic electricity to the beginner, and to leave enlargement in details to our subsequent pages.

We may, however, in continuation of our present purpose, here briefly allude to the supposed influence of electrical currents in producing metallic veins and minerals in nature—a subject of great interest; but, as yet, one of which little is known.

Many able experimenters have succeeded in imitating, by long-continued, intense currents, of little quantity, acting on solutions of the ordinary metals and the earths, the products of the mineral kingdom. Many crystallised

minerals have thus been obtained; and, by a very simple voltaic action on sulphide of carbon, minute crystals, resembling those of the diamond, have been recently procured. That electrical currents traverse the earth, internal and external to its surface, is a fact that experiment has put beyond doubt; but how far such currents, whether of a local or general character, influence or cause the production of minerals and metallic veins, and, if so, how this is done, has yet to be satisfactorily determined.

On this subject Professor Ansted remarks as follows:—"An attempt has been made to account for the phenomena of mineral veins by the agency of electricity; and the advocates of this hypothesis consider, that, by referring to electro-chemical action, many of the most characteristic and remarkable of the facts that have been observed may be satisfactorily explained. The great improvements and discoveries that have, of late years, been effected in this branch of science, and the certainty that electricity is a most powerful force, acting incessantly, affecting even the minute structure of inorganic bodies, corresponding almost with the vital principle in its power of removing, rearranging, and selecting the particles of dead matter, render every suggestion, with reference to this force, worthy of the most careful attention.

"The experimenter to whom science is chiefly indebted for the original researches on which the electrical theory of mineral veins is founded, was Mr. Robert Were Fox, who greatly distinguished himself by a vast number of investigations on the mutual relations of electricity and magnetism, and their mode of mineralising action.

"Assuming the existence of fissures, produced in the solid substance of the earth's crust at various times, and taking it for granted also that they penetrate to great depth, are exposed to a high temperature, and must have been filled up progressively, Mr. Fox has shown the probability there is of heated water having been circulated in them by ascent and descent, and the certainty that quartz and earthy substances might be deposited from water in that state. He then proceeds to explain, that in such fissures, filled with metallic and earthy solutions, the different sorts of matter on the sides must necessarily produce electrical action, which might be rendered more active by the unequal temperature of the water and the walls of the fissure. Currents of electricity thus generated would pass more easily in the fissures than through the rocks, and they would pass in directions conformable to the general magnetic currents of the district, and, therefore, east and west, or somewhat to the north and south of these points, according to the position of the magnetic pole [of the earth] at the period when the process was going on.

"Electrical currents, thus circumstanced, would deposit the basis of the decomposed earthy and metallic salts on different parts of the rocky boundary of the vein, according to the momentary electrical state and intensity of the different points; and the nature and position of the rocks would be influential in determining these conditions. When, by such processes, particular arrangements had happened, new actions might arise, and, amongst them, a series of secondary phenomena, such as the transformation of ores without change of form—a fact otherwise very difficult to comprehend. Lateral rents might also be filled by virtue of these new actions, even though they were not in the most favourable lines of an electrical circulation.

"In confirmation of his views, Mr. Fox actually succeeded, by direct experiment, in forming well-defined metalliferous veins by means of voltaic currents operating under circumstances resembling those supposed to have occurred, and which sometimes do occur, in Cornwall."

In explanation of the last few words in the preceding quotation, we may add, that Mr. Fox succeeded in proving that the circulation of a current analogous to, or identical with, the voltaic current, really takes place in mines whence copper is procured; and although, to a large extent, he rests his theory of the electro-chemical production of metal veins, or lodes, on the more general electric currents that exist in nature, and of a less special character than such as we have just named, still it does not follow, that if he erred as to the source of the current, the current itself shall not be capable of the effects ascribed to it.

When Mr. Fox first published the results of his researches, we attempted to obtain, on the small scale, similar results to what we have ourselves observed in various mines in all parts of these islands. In nearly, if not every, mine that we have visited, it was evident that porosity and fissure of the rock, with the percolation of water, are all but universal conditions attending the production of mineral veins in which anything like a crystal-like structure could be detected. This point we specially mention, because many may object that iron ores are all but universally amorphous; that is, without any definite shape as regards the mass. In this respect, indeed, the appearance of any largely worked veins of iron scarcely differs materially from a mass of common clay. But Mr. Fox's remarks, and our own experiments (to be related), are intended chiefly for such metals as copper, and others that can commonly assume the native or metal state, and that can also resist the action of the oxidising influence of air and moisture. It is well known, by the remains of ancient bronze, copper, and lead objects of antiquity, that those metals will resist the action of air and moisture for centuries, or even scores of centuries, whilst a similar object of iron would be destroyed in comparatively "no time." Arguing on this fact, we may safely conclude, that what we now find as a common condition of copper, &c.—namely, its discovery from small crystals to immense masses in the native or metallic state—may have equally, at one time, been a condition of iron; but that, in process of ages, its oxidation, or conversion into carbonate or sulphide, might have been effected. Not that we in any way offer an opinion to that effect as the cause

of the present condition of iron ores. On the contrary, we hold entirely different views, the expression of which, however, would lead us into geological questions utterly apart from the subjects of this work. The preceding remarks are merely made to show, that whatever may have been the cause of the deposition of any form of iron ores, their present condition is not necessarily indicative of that cause ; simply because the affinities of metallic iron for oxygen, sulphur, &c., are so great, that a few years' exposure of the best iron plate is sufficient to destroy its metallic character, if it be entirely unprotected from the influences just named. Railway, engineering, and ship-building experience fully confirms the truth of these observations.

Returning now to the question of the production of metallic ores by electrical currents, we may state that, on Mr. Fox and Mr. Crosse having published the results they had arrived at, we attempted, on the principle they laid down, to imitate the production of mineral veins on the small scale, and adopted the following method :—

A cylinder was made of plaster of Paris and chalk, six inches long, and two inches in diameter; and, whilst still moist, two copper wires were inserted, one at each end. The annexed cut represents the arrangement employed. *a* is the earthen cylinder; *b*, *c*, wires proceeding from the battery, and covered with sealing-wax ; or, what is still better, gutta-percha, to protect them from the fluid until they enter the cylinder, *a*. The dotted lines indicate the extension of the wires inside the cylinder, the two ends terminating at a distance of two inches from each other. The whole was contained in a trough filled with a moderately strong solution of sulphate of copper, to which a little sulphate of iron was added. The reason we used the latter with the copper salt was, that, as an almost universal rule, iron salts are associated with the metallic veins of less oxidisable metals in nature. The cause of this has not yet been discovered; but it remains an indisputable fact in regard to most veins of metal, from gold to copper. The wires, *a*, *b*, *c*, were connected with a battery of twenty cells of Daniell's constant battery, of the shape illustrated by Fig. 139, p. 230, *ante*, the copper cylinder being 12 inches high, and 3½ inches diameter. A simple solution of sulphate of copper was used as a charge for the copper side, its strength being kept up by occasional additions of crystals of sulphate of copper. The zinc was excited by a weak solution of common salt. By such comparatively feeble charges the action of the battery was kept equable for several weeks ; and no necessity occurred for changing the zinc-exciting liquid. Evaporation was prevented by covering the top with thick brown paper.

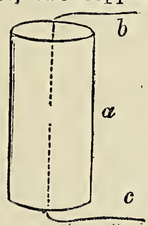


Fig. 157.

At the end of two months the cylinder was removed from the trough, and broken. It contained a considerable quantity of pure metallic copper, in a crystal and nodule state, precisely resembling what may be frequently seen in copper mines. Besides, there were deposits of the blue carbonate, together with the brown stain of the peroxide of iron. In fact, to those who are acquainted with the various appearances that may be seen in a copper vein, excepting the absence, of course, of sulphide of copper, the appearances were precisely similar to those that are presented in nature.

It is probable that some of our readers may feel inclined to try a similar experiment; for even to persons lacking a taste for science, the result cannot but be both pleasing and interesting; and the following method may be pursued with an average certainty of success.

Take a common garden-pot, and fill it six inches deep with plaster of Paris, by stirring some of that substance in powder, as obtained from the Italian shops, with water, in a basin, and then pour the mixture into the garden-pot. Solder a copper wire—say two feet long—to a plate of zinc, and one of copper, each about four inches square, the plates being, of course, at the opposite extremities of the wire, which may be No. 16 gauge. Fill a trough, to a depth of four or six inches, with a strong solution of sulphate of copper, and in this place the plate of copper resting flat on the bottom of the trough. Rest the garden-pot containing the plaster of Paris on the copper plate, and then, bending the wire, introduce the zinc into the top of the garden-pot, forcing it a small distance into the plaster of Paris. Fill up the top of the garden-pot with a solution of common salt. The arrangement will thus appear as represented in the annexed cut, in which B is the basin or trough holding the copper solution ; C, the plate of copper, on which the pot, G, rests ; P, the plaster of Paris in the pot ; W, the copper wire, which should be coated with varnish, or gutta-percha, for the whole distance it reaches through the liquid ; Z, the zinc plate, resting in the solution of common salt, S.

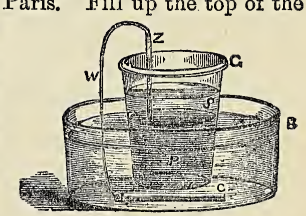


Fig. 158.

By this arrangement, a current of electricity will be generated between the zinc and copper plates, through the plaster of Paris, and the hole at the bottom of the garden-pot. After a few weeks, metallic copper, with its oxide, carbonate, &c., will be deposited between the zinc and copper plates, presenting precisely the same appearance as in nature. To prevent the necessity of renewing the liquids, it is best to cover the whole apparatus up, which will, of course, prevent evaporation.

Those of our readers who have been accustomed to use Daniell's battery, will have frequently found the same results accrue at the bottom of the earthenware porous cells. After

being some time used without being washed, metallic copper will form *inside* the cell, especially if the zinc rest on its surface; and it was from noticing this fact that we were led to construct the simple arrangement just described, as illustrating the production of metallic masses by the voltaic current.

It, of course, by no means follows, that because we can imitate, by a certain method, the results of nature, that in nature the *modus operandi* should be the same. We should much regret the supposition, that because we have detailed the previous experiments as affording results so identical with natural effects, we believe that mineral veins are similarly formed. All that we propose in this, is to show that electricity can produce such effects; but hesitate to offer an opinion that metallic veins are so produced. The *data* that we possess in science are far too few to permit of such a course being soundly philosophical.

The familiar and beautiful experiment of hanging a piece of zinc in a solution of acetate of lead, depends on the exertion of electro-chemical action, after the manner previously described; but perhaps one of the most interesting and elegant results of the production of metallic crystals is detailed below. We first observed them accidentally, in attempting to deposit metallic tin; and have obtained crystals of that metal a couple of feet long, and of the most brilliant polish, by the following method:—

A strong solution of sal-ammoniac is to be made in water; and, after filtering it, should be poured into a deep glass jar. An ordinary confectioner's glass answers extremely well. The battery required may be either a single cell of Smee's, or one of Daniell's, 6 inches high, and $3\frac{1}{2}$ inches in diameter. To the wire proceeding from the copper or silver of the battery, attach a strip of tin (not tinned iron), as sold at the plumbers' shops, and immerse the bar wholly in the sal-ammoniac solution. Bring a copper wire from the zinc end of the battery, and only just dip its edge below the surface of the sal-ammoniac solution. After a few hours, crystals of tin will commence to form at the extremity of the latter, or the cathode of the battery, shooting, in every direction, in points, needles, and flat plates, according to the action of the battery. It is impossible to exaggerate in the description of the beauty of these crystals, if the whole is carefully managed. They continue to increase until a bunch, as large as an ordinary one of grapes, is produced. If the bunch be then carefully removed, and abundantly washed in warm distilled water, the crystals may be preserved for almost any length of time without loss of polish, and form a handsome ornament for preservation under a glass shade, the tin being absolutely pure, and, consequently, barely liable to oxidation.

Such are some of the most interesting features of electro-chemical action, apart from its application to electrotyping. We next proceed to describe some of—

The Physiological Effects of the Voltaic Current.—Although, at the present day, voltaic electricity is not had recourse to for medical purposes in respect to the direct current, the latter being used to excite some form of induction in copper wire, familiarly known as the coil or shock-giving machine, still some interesting facts are connected with the physiological effects of electricity as evolved by the voltaic battery.

At p. 226, *ante*, we pointed out, that if a half-crown be placed on one side of the tongue, and a piece of zinc on the other side, and the two metals be brought into contact at their other edges, a peculiar sensation is at once observed, the developed electricity affecting the nerves of the tongue, and a metallic taste being also perceived.

Again, at p. 228, *ante*, when describing Volta's pile as one of the earliest forms of the battery, it was stated, that if the terminal wires of the pile, consisting of, say from thirty to fifty alternations, were grasped by the hands, moistened by salt and water, an electric shock would be perceived. If a piece of silver be forced up high between the cheek and gum of the upper jaw, and a piece of zinc placed in the mouth be brought into contact with it, the optic nerve is affected; for, at the moment the metals are caused to touch, a flash of light is perceived in the eye, if that organ be closed to external light.

A series of thirty to fifty cells of any of the modern forms of voltaic batteries, gives a strong shock to the moistened hands. But the voltaic shock, like all its other effects, is continuous; and hence, so long as the wires conducting the current of such a series above mentioned be held, the arms of the experimenter are affected. The shock of frictional electricity is quite opposite in character; for the moment the Leyden jar is discharged, the physiological effect at the same time ceases.

Again, whilst, through the tension of static electricity, its effects may be propagated through an extended chain of individuals, joined together by their hands, without any sign of diminution of force, each additional member of the chain, if the voltaic electric current be employed, greatly lessens the force of the shock, until, by increasing the number, its effects may become quite imperceptible. In this fact we perceive another illustration of the difference that exists between the high tension and low quantity of static electricity, and the high quantity, but low tension, of the voltaic current.

The shock from 100 cells of a Grove's battery is very severe, and all but intolerable, because continuous; hence the necessity of covering the conducting wires with some non-conducting substance when such arrangements are experimented with.

It would be impossible for us here to enter into any discussion as to the value or use of the voltaic current in a medicative point of view. Highly different opinions have been held respecting this, and it is a subject specially connected with physiology. At a previous page (see p. 211, *ante*), we have made a few remarks

on this subject, deprecating the hasty generalisation of some who have ventured to suggest that electricity is the vital principle. The effects of the voltaic current, after death, on the bodies of animals or criminals that have been suddenly deprived of life, have also been, in part, dealt with. On the small scale they may be easily investigated by operating on freshly killed rabbits, but which are best destroyed for this purpose by immersion in a box kept constantly filled with carbonic acid gas, produced from a mixture of chalk and hydrochloric acid in a bottle, from which should proceed a bent pipe, carried to the bottom of a box containing the animal. This mode of killing it, or that by administering hydrocyanic acid, causes a painless death. A pointed wire may then be inserted into the spinal marrow, and another into the nerves of the legs. When the two conducting wires of a battery of thirty or forty cells are brought into contact with those fixed in the animal, powerful muscular contractions take place; and, possibly, if the body be still warm, and, consequently, the blood uncoagulated, the effect may be so violent as to cause the rabbit to spring from the operating table. It is not impossible that even life itself may be restored. Experimenting once on a dead cat, the contraction of the muscles of the jaws was so great, that we noticed a piece of thick copper wire bitten clean through by the teeth of the animal.

This capability of inducing involuntary muscular contraction, in apparently dead persons, in whom asphyxia has been caused by immersion in water, or in gases, such as carbonic acid, has been turned to valuable account. Despite every ordinary attempt being made to restore breathing by artificial means, such as the excellent method proposed by the late Marshall Hall, injection of tobacco-smoke, &c., &c., it is often impossible to cause such an action of the muscles of the chest and stomach as shall expand and contract the lungs, and so produce the mechanical concomitants of respiration. A ridiculous idea is all but universally prevalent, that much water passes on to the lungs in drowning. Such cannot be the case by any possibility, the mouth only becoming filled with water. But the cause of insensibility is the retention of the carbonic acid, produced by the oxidation of the carbon of the blood during the last act of respiration; and if this can be removed, much chance, within certain limits, exists of restoring suspended animation. The voltaic current, or that induced by the voltaic current in the secondary coil of the "coil machine," admirably answers the purpose in many cases. A spasmodic action of the muscles of the chest results, and the resident carbonic acid being expelled, fresh oxygenated air is inspired, and an act of respiration occurs.

Sensitiveness to the shock of the voltaic battery is greatest in persons having a moist skin; for the current requires a good conducting surface to affect the nerves of the parts to which the terminals of the battery are applied. For all ordinary purposes, a battery of ten cells, of Smee's or Daniell's arrangement, is sufficient. The ends of the conducting wires should terminate in a thin silver or brass plate, so that the latter may be placed, one above, and the other below, the part affected. Numerous arrangements have been proposed in place of, but partaking of the nature of, the voltaic battery; but such it is not our duty either to notice individually, or to describe.

CHAPTER IX.

THEORIES OF VOLTAIC ELECTRICITY.

It rarely happens that he who discovers a few new facts in science can resist the temptation of at once commencing to form a theory in which to aggregate the phenomena newly discovered, in such a manner as to account generally for their cause, and to predicate the application of such theory to other phenomena that may subsequently appear. Even some of the most eminent philosophers of the present and earlier days have thus been betrayed into folly. Indeed, scarcely more than thirty years have elapsed since the late Lord Rosse's telescope showed the nebulous theory not to have the least foundation; in fact, the great power of the instrument he constructed, showed the *existence* of stars, previously thought as being in course of manufacture. Eminent meteorologists speculated, not many years ago, on the possibility of our immersion in the tail of a comet being the cause of influenza, cholera, and many other of the ills of flesh. One of our most eminent chemists, who discovered the metallic bases of potass, soda, &c. (see *ante*, p. 244)—we mean Davy—was so enraptured with the novelty of his discovery, as to suggest that volcanoes were caused by the contact of potassium and sodium, or the alkaline metals with water, in the bowels of the earth—a theory little less absurd, when tried by question of fact, than the theory of digestion, &c., by the ancients, who assigned the operation of those functions to the activity of an internal imp. But we need not go back a year to show how ridiculous men become who leave sober fact to theorise; for a

portion of the scientific world is now occupied with the consideration, or dissemination, of the theory that man is simply an improved and progressive result of development from the rhizopod, saurian, quadruped, ape, gorilla, culminating in the external form of humanity, but admitted by all to partake of the intelligence of the Deity. Ardently would we recommend the study of Newton's *Principia*, Bacon's *Organon*, and Faraday's *Researches* to such individuals, that their imagination may be chastened by sober reasoning, so that the theories they propound should rather be founded on fact than fancy.

Voltaic electricity, like other branches of experimental philosophy generally, has been no exception to the mania of theory-production. As already stated at p. 225, *ante*, Galvani ascribed the effects he witnessed in his early experiments to the electricity of the animal he experimented on. After him came the theory of Volta, which ascribed the effects as due to the contact of dissimilar metals. In Series xvi. of Faraday's *Researches*, he enters on the question in the following manner. And here we may remark that it is to him we are indebted for proving that chemical action, and not contact, is the source of the voltaic current. He commences by observing—

"What is the source of power in a voltaic pile? This question is at present of the utmost importance in the theory, and to the development, of electrical science. The opinions held respecting it are various; but by far the most important are the two which respectively find the source of power in *contact* and in *chemical* force. The question between them touches the first principles of electrical action; for the opinions are in such contrast, that two men respectively adopting them, are thenceforward constrained to differ, in every point, respecting the probable and intimate nature of the agent or force on which all the phenomena of the voltaic pile depend.

"The theory of contact is the theory of Volta, the great discoverer of the voltaic pile itself; and it has been sustained since his day by a host of philosophers, amongst whom, in recent times, rank such men as Pfaff, Marianini, Fechner, Matteuci, Karsten, Bouchardat; and, as to the excitement of the power, even Davy—all bright stars in the exalted region of science. The theory of chemical action was first advanced by Fabroni, Wollaston, and Parrott; and has been more or less developed since by Œrsted, Becquerel, De La Rive, Ritchie, Pouillet, Schönbein, and many others; amongst whom Becquerel ought to be distinguished as having contributed, from the first, a continually increasing mass of the strongest experimental evidences that chemical action always evolves electricity; and De La Rive should be named, as most clear and constant in his views, and most zealous in the production of facts and arguments from the year 1827 to the present time." This was written by Faraday in 1840. He continues—

"Examining this question by the results of definite electro-chemical action, I felt constrained to take part with those who believed the origin of voltaic power to consist in chemical action alone." He then refers to a paper, published by him in 1834, in which he showed that chemical action, derived from the circulation of a voltaic current, could be effected without the contact of the two plates of the cell; and as the experiment he refers to has been one generally used from that day, to prove the source of the voltaic power to be chemical action, we shall adduce Faraday's remarks, and illustrate the apparatus he constructed. Speaking of the compartments of the contact and chemical theories, he observes (§ 879)—"I thought it essential to decide this question by the simplest possible form of apparatus and experiments, that no fallacy might be inadvertently admitted. The well-known difficulty of effecting decomposition by a single pair of plates, except in the fluid exciting them to action, seemed to throw insurmountable obstruction in the way of such experiments; but I remembered the easy decomposability of the solution of iodide of potassium; and seeing no theoretical reason, if metallic contact was not essential, why true electro-decomposition should not be obtained without it, even in a single circuit, I persevered, and succeeded."

Here we must observe, parenthetically, that when Faraday thus experimented and wrote—viz., in 1834—all the modern forms of powerful voltaic batteries were unknown. Daniell's, Grove's, Smee's, &c., had not been thought of; indeed, the first of these was brought out not till two years later. Much more convincing experiments than the one now about to be related, as invented by Faraday, have been mentioned in the preceding pages. Thus a single cell of either Daniell's, Grove's, or any form of modern battery, is abundantly sufficient to decompose acidulated water, metallic solutions, &c. But none of these arrangements were then known, as Faraday only had such form of batteries as Cruickshank's, Babbington's, or Wollaston's, already described at p. 228, *ante*; and in all of which metallic contact was involved as a principle of construction.

To illustrate his views, Faraday suggested the following simple apparatus:—"If a piece of zinc and of platina be placed without contact in a vessel, V, of dilute sulphuric acid, and joined by means of a wire, a simple voltaic arrangement will result. If the wire be now supposed to be broken in the middle, and a body such as R inserted between the two ends, it is evident that a voltaic current, supposing one to take place, will be favourably circumstanced for passing through

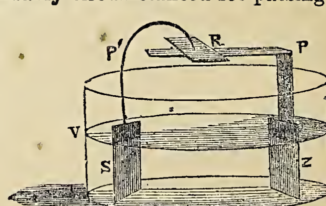


Fig. 159.

R and decomposing it, if capable of decomposition. Now, if R be a disc of bibulous paper, filled with a solution of iodide of potassium and starch, and laid for convenience on the flattened platinum electrode P, as represented in the diagram, whilst its upper surface is touched with the platinum wire P′, decomposition of the iodide of potassium ensues, as evidenced by the paper immediately turning blue. In this case it is evident there was no metallic contact.

"As long as the lower ends of the plates remained in the acid the electric current continued, and the decomposition proceeded at R. On removing the end of the wire from place to place on the paper, the effect was evidently very powerful; and on placing a piece of turmeric paper between the white paper and the zinc, both papers being moistened with a solution of iodide of potassium, alkali was evolved at the cathode against the zinc, in proportion to the evolution of iodine at the anode; hence the decomposition was perfectly polar, and decidedly dependent upon a current of electricity passing from the zinc through the acid to the platina in the vessel V, and back from the platina through the solution to the zinc at the paper, R.

"That the decomposition at R was a true electrolytic action, due to a current determined by the state of things in the vessel, V, and not dependent upon any mere direct chemical action of the zinc and platina [wire] on the iodide, or even upon any *current* which the solution of iodide might, by its action on those metals, tend to form at R, was shown, in the first place, by removing the vessel, V, and its acids, from the plates, when all decomposition at R ceased; and, in the next [place], by connecting the metals either in or out of the acid together, when decomposition of the iodide at R occurred, but in a *reverse order*. For now the alkali appeared against the end of the platina wires, and the iodine passed to the zinc, the current being in the contrary to what it was in the former instance, and produced directly by the difference of action of the solution in the paper on the two metals. The iodine, of course, combined with the zinc."

The preceding demonstration partakes of Euclidian precision. Lest any fallacy be admitted, Faraday tries more than one way of proving his point. As he remarks, it might have been possible that a current was generated between the end of the platina wire and the surface of the zinc; although this could not be the case, because the iodine travelled to the anode, and the alkali to the cathode, as above stated. But the bare possibility of such a result, at once determined him to show that, in this case, it did not occur; for, as we have seen, so soon as he converted the arrangement into an external cell, a current was generated between the zinc and the platina, reverse in order to the first one, and precisely of the same kind as occurs when a simple voltaic cell is constructed, such as is represented at p. 227, in the beginning of the article on voltaic electricity.

But although six years had elapsed, we find that, so late as 1840, the contact theory was still in the ascendant on the continent. In that year, in § 1,800 of Series xvi., Faraday thus summarises the chief views of the "contact" philosophers:—"Volta's theory is, that the simple contact of conducting bodies causes electricity to be developed at the point of contact without any change in the nature of the bodies themselves; and although such conductors as water and aqueous fluids have this property, yet the degree in which they possess it is unworthy of consideration in comparison with the degree to which it rises in the metals. The present views [1840] of the Italian and German contact philosophers, are, I believe, generally the same, except that, occasionally, more importance is attached to the contact of the imperfect conductors with the metals. Thus Zamboni considers (in 1837) the metallic contact as the most powerful source of electricity, and not that of the metals with the fluid; but Karsten, holding the contact theory, transfers the electro-motive force to the contact of the fluids with the solid conductors."

Faraday goes on to describe other views; but expresses himself as agreed with De La Rive—"And I do not think that, in the voltaic pile, mere contact does anything in the excitation of the current, except as it is preparatory to, and ends in, complete chemical action."

It will be unnecessary for us to go over all the various arguments that the contact theorists maintained. Zamboni constructed what was called a *dry pile*, consisting of alternate leaves of metals, to the number of several hundreds; but it was plainly proved by Faraday, that the hygrometric moisture in the paper acted chemically on the most oxidisable of the two; and that, in this instrument, which approximates, in its manifestations, to that of the frictional machine, chemical action is the sole existing cause.

In § 1,803, Series xvi., Faraday thus enunciates his view:—

"The chemical theory assumes, that, at the place of action, the particles which are in contact act chemically upon each other, and are able, under the circumstances, to throw more or less of the acting force into a dynamic form; that, in the most favourable circumstances, the whole is converted into dynamic force; that then the amount of current force produced is an exact equivalent of the original chemical force employed; and that in no case (in the voltaic pile) can any electric current be produced without the active exertion and consumption of an equal amount of chemical force, ending in a given amount of chemical charge."

Referring our readers, by the previous quotations, to a period when we well remember how vigorous the contest was between "contact" and "chemical" theorists, in reference to the actual cause of the power of the voltaic pile; and now writing at a period when the contact theory is utterly exploded, and the chemical one universally accepted, we cannot help being surprised at the persistent manner with which prejudiced minds adhere to preconceived notions. An analogous case occurred in respect to the discovery of Davy, that chlorine was an elementary

body. The chemists of that period resolutely, as a majority, opposed his view; and some years elapsed before Davy was universally admitted to be correct in his views, although now no one would venture to doubt their truth. Faraday certainly must have been the most fortunate of experimental philosophers, if an acceptance of one man's theories by all philosophers be an evidence. He, in early years, had to combat false theories of all kinds; invent and establish others entirely new, and opposed to those of his day; and, long before his death, he found that what he had promulgated by experiment and legitimate induction, had become universally recognised as a truthful exposition of the laws of the sciences he had investigated, and the bases of applications that have never been equalled in their philosophical and social importance.

Before proceeding further in these investigations, we shall have to describe an instrument—the galvanometer—of great importance in respect to the quantity of the voltaic current. The apparatus by which water is decomposed, and called the voltameter—because the amount of liberated gases, for any period of time, by voltaic action, is made a measure of the amount of force passing—has been described at p. 242, *ante*; but is far too crude an instrument to be employed in refined observations, and, indeed, requires a powerful battery to set it in action.

The galvanometer, and the principles of its construction, may be described as follows; and, for this purpose, we must briefly trench on some phenomena of magnetism and electro-magnetism.

About the year 1819, Œrsted, the celebrated electrician, whose name has been already mentioned in the preceding pages, made the discovery, that a wire conveying a voltaic current, had the power of deflecting a magnetic needle from its position, and of maintaining that deflection so long as the current passed over or under it—a discovery that, in its subsequent application in the electric telegraph, has been of the highest importance to mankind. A very simple apparatus, and a single cell of any modern form of battery, will be sufficient to illustrate this fact. Thus, in the following cut, a copper wire is represented as bent into a parallelogram, its two ends being kept apart, and fitted with cups for holding a little mercury. In the centre a magnetic needle is suspended on a pivot, so that it may be free to move in any horizontal direction.

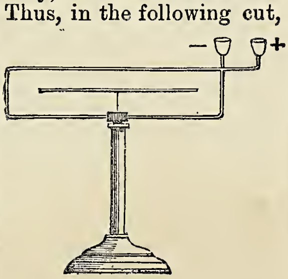


Fig. 160.

For the purpose of trying the experiment, the apparatus should be so arranged that the copper wire shall be exactly in the same line over and under the needle; that is, both should point in the same line as the polarity of the needle indicates. If the two conducting wires of the voltaic cell be next introduced, one in each of the mercury cups, at the instant the current passes by the copper wire, the magnetic needle will be deflected from its original position—right or left, according to the direction that the current takes. If proceeding from north to south, the needle will be turned to the right hand; and if from south to north, the needle will diverge to the left. Thus, in the following cut, *a* and *b* are supposed to be the

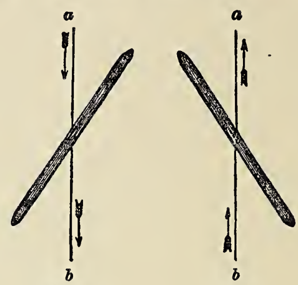


Fig. 161.

wires conducting the current. In No. 1, the direction of the current is supposed to be from north to south; whilst, in No. 2, the direction is the reverse of that. In No. 1, *a* is supposed to receive the end of the wire proceeding from the negative plate of the battery, or the electrode, called the anode; while *b* is supposed to be the cathode, or that wire which is attached to the zinc of the battery. In No. 2, the position of the electrodes is reversed; or, what comes to the same thing, if the current be sent beneath instead of above the needle, with the electrodes in both cases similarly placed, the effect on the needle is reversed to what it is when the wire or current traverses above it.

In this simple experiment, not only is it proved that electricity and magnetism are mutually related; that an electrified wire affects a magnetised body; and that, also, the needle may be acted on by a voltaic current; but, by carrying on the experiment a little further, we can show how the deflection of the needle so produced may be made a *measure* of the *quantity* of electricity passing in a current. For this purpose, the wires of a single cell of a Smee's, or any other battery, should be placed, respectively, in the cups of the instrument illustrated in the preceding cut. As long as no exciting liquid is in the battery, of course, no current can be afforded; hence the needle will be unaffected. But if a little acid be poured in, so as to excite only a *small* portion of the battery surface, the needle will be slightly deflected. On pouring more of the exciting liquid into the battery, a greater amount of its surface will be called into action, and, consequently, a larger quantity of electricity will be set in motion. Resulting from this increased quantity, the needle will be still more deflected. Continuing to pour in more of the exciting fluid, the deflection of the needle will increase until the battery be fully charged, when the maximum of deflection will take place. If a Smee's battery

be employed, it is better first to attach the wire to the cups whilst the plates are out of the acid water; they may then be gradually lowered into it, and, of course, the same result will accrue as we have already described.

The instrument, therefore, very accurately indicates the *quantity* of a passing current; for the greater that is, the larger is the deflection of the needle.

By such a method it is evident we may compare the relative value of a battery cell in respect to the amount of quantity it produces. Thus, if a Grove's single cell, exposing the same area of negative plate in action, be compared by it with one of either Smee's or Daniell's, the deflection of the needle will be far greater as produced by the nitric acid battery than afforded by the others; because, for the same area of negative surface, Grove's battery produces a much larger quantity of electricity. Again, the effect of an increase in the strength of an acid solution, in producing greater *quantity*, may be, in like manner, investigated. If a Smee's battery, for example, be charged with river water, and the wires be connected with the deflecting instrument, the needle will scarcely move. On adding a little sulphuric acid to the water, and stirring it well up, the deflection will increase, advancing still more as more acid is added, until the maximum charge of the battery and the greatest deflection of the needle have been arrived at.

In the preceding pages, we have repeatedly stated how much the size of the negative plate of the battery, and the strength of the charge, influence either, or both, the amount of quantity produced; but, as yet, have only mentioned the method of measuring that increase by observing the results in melting wire or in decomposing water by the voltameter, described and illustrated at p. 242, Fig. 154, *ante*. But it is evident that such methods are crude and uncertain, whilst that afforded us by the deflection of the magnetised needle, is almost as exact as the index of time afforded by a good clock.

Such an instrument, however, as that illustrated by the preceding cut would be of little value in refined investigations; and accordingly, whilst the same principle is involved, the galvanometer, employed in voltaic researches, is a much more complicated apparatus. A single needle is not employed; but two are so arranged that the north pole of one shall be over the south pole of the other, as represented in the following cut. By this arrangement the needle is rendered *astatic*; that is, the polarity is destroyed, whilst the magnetic attractive power remains. The two needles are fixed on a piece of straw or other light material, for every care

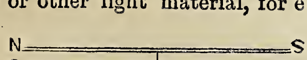


Fig. 162.

is taken to reduce their weight, so that the utmost delicacy may be ensured.

Having thus obtained an astatic needle, the construction of the galvanometer may be explained and illustrated as follows:—*a*, Fig. 163,

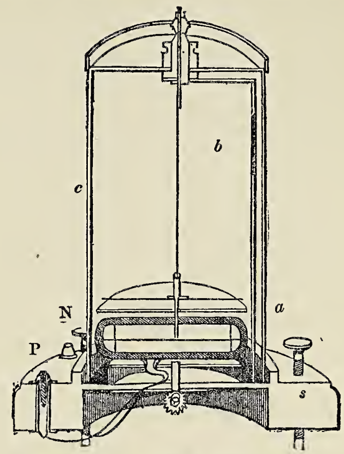


Fig. 163.—The Galvanometer.

represents the needle suspended by a thread, *b*, from a pivot over it, within a glass shade, *c*, used to keep off currents of air. Over and under the needle, *a*, the thick black parallelogram, with curved ends, represents a long coil of very fine copper wire, covered with silk, and taking the place of the simple wire shown in a preceding cut (Fig. 160). The reason a long coil is used is, that the greater the number of convolutions, the greater is the effect on the needle from the same current; hence the instrument may be constructed of such delicacy that the most minute quantity of current passing will be indicated. Over the needles, to which is generally attached an index (or one of the needles occasionally answers the same purpose), is a card, divided into

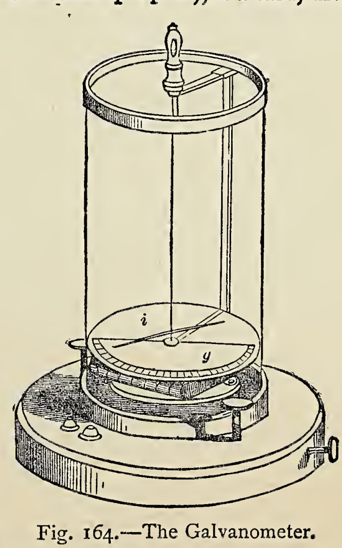


Fig. 164.—The Galvanometer.

360 degrees, and parts of a degree; or into four quadrants, each at 90°: and this serves to show the amount of deflection from zero, or 0°, as the

measure of the quantity of current passing. P, N, are two mercury cups, or binding-screws, intended to receive the conducting wires of the cell or other source of the current; and by means of three screws, one of which is shown by *s* in the cut, the instrument is put into a perfectly horizontal position, and the astatic needle is, consequently, kept level.

In the preceding cut (Fig. 164), the instrument is represented as it appears; and the index, *i*, or upper needle, with the graduated card, *g*, will be noticed.

The galvanometer is of the utmost value to the electrician, for experimental research, for regulating and noting the power and constancy of a battery, and also in telegraphy. In fact, the needle telegraph—at one time universally employed, but which is now replaced by more complete instruments—is constructed on precisely the same principles as the galvanometer, only that the needles, coil, &c., are placed vertically, instead of horizontally.

Having thus explained the construction and use of this valuable method of measuring the quantity of the voltaic current, we resume our inquiry into the laws of the science.

It will be evident that, from what has already been stated, frictional and voltaic electricity are identical in all respects as regards their nature, although certain of their conditions, and the mode of obtaining them, differ, the latter essentially, and the former in degree. It would require a comparatively enormous charge of static electricity to affect the needle of the galvanometer, because of the comparative absence of quantity in electricity of high tension; whilst the most minute current of voltaic electricity is capable of producing that effect. On the other hand, whilst a single cell of a voltaic battery does not, but in the least degree, diverge the gold leaves of the electrometer or electroscope, the slightest disturbance of electricity by the friction of glass, &c., is capable of producing that effect. The pile of Zamboni (already described as consisting of a large number of metallic paper discs, arranged after the style of Volta's pile, and enclosed in a glass tube capped at each end with brass) will, however, diverge the gold leaves, set bells ringing, and otherwise give imitations of the effects of static electricity, although its force is generated like that of the voltaic current by chemical action. It may, therefore, be considered as a kind of connecting link between the current and static electricities. Again, a hundred cells of almost any form of voltaic battery will diverge the leaves of the electrometer. But the best form of battery for the purpose of showing the identity of static and current electricity, is what is called a water battery. The size of each plate is a matter of no importance; for intensity and not quantity is required. For example, a thousand of such cells as are represented in the *Couronne des Tasses*, at p. 227, *ante*, Fig. 132, charged with river or spring water, will answer exceedingly well for the purpose, and will afford effects strikingly alike to those presented by a small electrical machine.

The nearest approach that has yet been made in producing simultaneously, in one instrument, the effects of current and static force, is that of the *Induction coil*, in which, by the inductive action of a primary current traversing a short stout coil of copper wire, a secondary current is induced in another very long and insulated coil wound over the former. By such an instrument nearly all the effects of static and current force may be produced. The further description of this instrument would require us to anticipate many subjects that will be subsequently fully investigated. The power of the induction coil is, therefore, here simply named as being another connecting link in the chain of variously-produced "electricities."

We cannot study even the most elementary principles of the branch of science now under consideration, without being struck with the astonishing variety, influence, and extent of the hidden powers of nature. That the friction of a piece of glass or sealing-wax, and the solution of a few grains of metal, should set free forces of heat, light, magnetism, chemical action, by the development of electricity, would, in ancient days, have been considered as a direct intervention of the power of the Deity, and supernatural to man; indeed, very likely would have subjected its discoverer to the terrors of his fellows, and, most probably, led to his immolation in the cause of science. But, in this day, such results are actually a necessity of life; and are constantly, as in the electric telegraph, being called upon to minister to our wants, wishes, hopes, joys, and fears. Half a century ago, indeed, the present application of electricity, in various ways, now so common, would have been treated as a most visionary project, scarcely inferior, in its imaginary character, to the Utopia of Bacon.

The errors of early discoveries, however, often turn to good purposes; and, in this respect, the theories that were at first propagated to account for the production of voltaic electricity, induced so many to enter the field of investigation, that, through so many workers, the science has advanced to perfection in one lifetime, whilst other branches have had to struggle on for existence through centuries. Fortunate was it that such rigidly exact experimenters as Faraday, Ampère, De La Rive, Œrsted, and their contemporaries, were induced to take up the earnest study of the science. In no other department of philosophy do we find greater painstaking to obtain accurate results, and in none have such careful labours been more amply rewarded.

At a previous page we gave some account of experiments with a form of nitric acid battery, in which we described some anomalous results (see *ante*, p. 233); and some facts that we noticed may be here conveniently laid before our readers. If the porous cell of a nitric acid battery be filled with strong nitric acid, or a mixture of strong sulphuric and nitric acids, and a plate of copper be substituted for the usual platina one, as in Grove's battery, the following results take place. At first no action is perceived on the copper, and if that plate and

the zinc are connected by a fine metallic wire, the latter will be melted. After a short time, a violent action will commence on the copper, which will be dissolved, forming nitrate of copper; yet a powerful current will be generated, the copper acting still as a negative plate. Almost precisely the same results occur with the use of passive iron, already referred to at a previous page.

Perhaps the greatest support that has yet been given to the chemical theory of the cause of the force of the voltaic pile, was the construction, by Mr. Grove (the inventor of the nitric acid and platina battery previously described), of a gas battery, in which it is impossible for the contact theory to have the least countenance, for only one metal is used. The following cut represents one of these arrangements. It consists of any number of vessels, partly filled with acid water, to act as a conducting medium. In each vessel is plunged a glass tube, into which has been soldered a platina plate, extending throughout the internal length of the tube. Each vessel contains two of these tubes, one being filled with oxygen, and the other with hydrogen; the oxygen tube of one vessel being connected with the hydrogen tube of the next, in a precisely similar manner as are the alternate plates of the cells in an ordinary battery; but, in this case, the two gases take the place of the metals, the platina employed in Mr. Grove's arrangement undergoing no action. As in the ordinary battery, a conducting wire extends from each end tube; that is, one from the oxygen and one from the hydrogen, just as the wires are connected with the last plates of a common two-metal battery. In Mr. Grove's first series of fifty cells, the platina was covered with platina powder, similar to the silver plate of Smee's battery (see *ante*, p. 234), so as to assist, by capillary action, the rise of the liquid to the surface of the platina; for it is the surface of that metal, open to the gas in each tube, that is effective in producing the current.

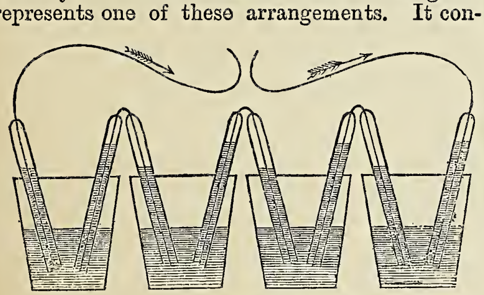


Fig. 165.—The Gas Battery.

With such an arrangement of fifty cells, a shock was received that proved painful, if taken by one person only, and was felt through five, with the hands joined together. The needle of the galvanometer was deflected sixty degrees; a bright spark was given, visible in daylight, between two charcoal points; water, acidulated by sulphuric acid, iodide of potassium, and various salts, were decomposed just as when an ordinary voltaic battery is employed. The tension produced was sufficiently great to affect a gold-leaf electrometer. It is evident, in this case, that synthesis is the direct result of the battery action, and is, probably, its cause; for gradually the gases disappear, and water is formed. The hydrogen in this battery is the analogue of the zinc in the common one. It undergoes oxidation to form water, just as, in the voltaic cell, zinc becomes oxide of zinc; and, on the other hand, the oxygen assumes the function of the negative plate of the common cell. The consumption of the two gases proceeds exactly as would be indicated by their chemical equivalents, and the ratio of their weight to their volume; for, as stated at p. 241 *ante*, double as much, in volume, of hydrogen is given off during decomposition in the voltameter, as there is of oxygen. So in the gas battery, two volumes of hydrogen disappear for one of oxygen.

Although we have stated that synthesis is the chief externally seen operation, result, or cause of the action of this gas battery, it must be borne in mind that decomposition must also ensue; for, of course, it is not the oxygen of the one tube that unites *directly* with the hydrogen of its fellow. That, of course, is physically impossible, inasmuch as the two gases are separated by the subjacent liquid. The action is, that the oxygen of the water in the hydrogen tube quits that liquid as it rests on the face of the powder of platina on the platina plate, to unite with the free hydrogen, in the gaseous state, in the tube; and a chain of decomposing particles or molecules extends thence to the oxygen tube, just as, in the common battery, the oxygen of the water attaches itself to the zinc, whilst the hydrogen is evolved at the copper (see p. 227, *ante*, where an elementary battery was described). So that actually synthesis and decomposition proceed just as much in the gas battery as in the ordinary voltaic cell.

In explaining the action of the battery, Mr. Grove remarked, on its first production—"We may suppose that, when the circuit is completed at each point of contact of oxygen, water, and platinum in the oxygen tube, a molecule of hydrogen leaves its associated molecule of oxygen to unite with one of the free [oxygen] gas; the oxygen thus thrown off unites with the hydrogen of an adjoining molecule of water; and so on, until the last molecule of oxygen unites with a molecule of the free hydrogen [in the hydrogen tube]; or we may conversely assume that the action commences in the hydrogen tube."

As already remarked, this gas battery gives the *coup de grace* to the contact theory. Mr. Grove observes:—

"There are one or two theoretical points as to which the gas battery offers ground of interesting speculation: the contact theory is one. If my notion be correct [as stated in his previously quoted theory of the gas battery], I am at a loss to know how the action of this battery will be found consistent with it, if, indeed, the contact theory assumes contact as the efficient cause of voltaic action; but admit that this can only be

circulated by chemical action. I see little difference, save in the mere hypothetical expression, between the contact and chemical theories; any conclusion which would flow from the one, would likewise be deducible from the other. There is no observed sequence of time in the phenomena; the contact, or completion of the circuit, and the electrolytical action, are synchronous. If this be the view of contact theorists, the rival theories are mere disputes about terms. If, however, the contact theory connects with the term *contact* an idea of force, which does or may produce a voltaic current independently of chemical action—a force without consumption—I cannot but regard it as inconsistent with the whole tenor of voltaic facts and general experience."

It may here be noticed, that it is by no means necessary to employ two metals with exciting solution; for, by the different action of two liquids on one metal, a current may be produced. Thus, if a plate of zinc be fixed in a trough, so that it shall divide the latter into two water-tight cells; and if, on one side of the zinc, dilute sulphuric acid be poured, whilst a solution of common salt is introduced into the cell on the other side, a current will be afforded. Many combinations of this kind might be described, in which unequal or dissimilar actions of liquids on metals produce a current; but as these are more curious than useful, we need not enter into their description. Even a difference in the mechanical condition of a metal may produce a current. Thus, if, in the preceding experiment, one side of the zinc be rough, and the other smooth, and dilute sulphuric acid be added to *both* cells, a current will be established. If a plate of copper be suspended in a solution of sulphate of copper and dilute sulphuric acid, after a time it is more than probable that the upper part of the liquid will become of less specific gravity than the lower; and it will be soon perceived that the upper part of the copper plate will be acted on, whilst on the lower part copper is deposited. Indeed, having on one occasion left twenty Daniell's cells, twenty-two inches high, filled with a solution of sulphate of copper, the bottom solution being heavier than the top, all the upper parts of the copper were corroded. If a porous tube be placed in a small glass vessel, and filled with nitric acid, whilst the exterior is filled with hydrochloric acid, and a piece of gold leaf be put into the external glass vessel, and immersed in the hydrochloric acid, the leaf will undergo no change. But if a gold wire be inserted in the nitric acid, and made to touch the gold leaf in the hydrochloric acid, the leaf in this acid will be dissolved. It will represent the zinc of the ordinary voltaic circle, whilst the wire corresponds to any negative plate; and thus a current is produced that can be fully identified by the deflection of the needle of the galvanometer.

Before concluding these remarks on the theory of voltaic action, its cause, &c., it may be remarked, that even the action of the ordinary frictional electrical machine, and that of the hydro-electric machine, have both been attributed to chemical action. It is certain that, so far as any form of *glass* machine is concerned, the usual amalgam, consisting of mercury and zinc, or the two metals united with tin, has great effect in increasing the available amonnt of electricity. Early experimenters, especially those attached to the chemical theory of voltaic electricity, maintained that the oxidation of the oxidisable metals in the amalgam was the chief cause of the production of electricity by the glass machine. But if this be the case, how is it that the perfectly clean paper, as produced by the paper machine after its passage over the last steam cylinder, should present such torrents of electric sparks? We have frequently seen these of a length of six inches. Indeed, in many mills, where the heat has so dried the walls, grounds, &c., the friction of the driving-straps often produces so large an amount of tensional electricity as to inconvenience the workmen.

But some of our most efficient electrical machines, constructed of gutta-percha, ebonite, and other such substances, require no amalgam, and yet afford an equal amount of free electricity by simple friction of the rubber. Some years ago we had a 15-inch machine, the plate of which was made of rosin and gutta-percha, with rabbit-skin rubbers, that gave quite as good an effect as any ordinary glass plate machine of the same diameter; and was ready for action in all kinds of weather. To test the idea of amalgam, by its chemical action, improving the action of such a machine, on one occasion the rubbers were amalgamated. Instead of any improvement resulting, the action deteriorated; and, until new rubbers were fixed, and the plate was carefully cleaned, the machine was valueless. In our opinion, the office of the amalgam is to increase the number of points of contact between the rubber-surface and the glass. The high polish of the latter gives but few points of contact to the rubber in the glass machine. When, however, the rough surface of gutta-percha, and the rubber of rabbit fur, pass each other, the number of surfaces of contact is much greater, and, consequently, the amount of friction is increased. Again, the almost invariable practice, in putting on amalgam to the rubbers of an electrical machine, is to mix it with some greasy substance, intentionally to make it adhere to the rubber and glass surface. But it is evident that the effect of the grease would be to cover the surface of the amalgam with a protecting cover, shielding it from atmospheric oxygen. Now, unless the grease be employed in the manner stated, the amalgam has little effect. But, taking simply the mechanical view of the question, and supposing that the adhesion of the rubber to the surface of the glass is improved, and, consequently, at the same time, the friction is increased by increased surface contact, we venture to suggest that a sufficient reason for the enlarged effect of the glass machine by the use of an amalgam results.

In reference to the theory of the action of the hydro-electric machine, as arising from the friction of water, and first experimentally

proved by Faraday, we refer our readers to the remarks and experiments detailed at p.185, *ante;* and, from lengthened experience with the machine there described, we fully concur with him in all respects. Faraday says, in Series xviii., § 2,106—"With dilute sulphuric acid in the steam globe [see description of the apparatus he used, given at p.184, *ante*], varying from extreme weakness to considerable sourness, I used tubes and cases of zinc, but could obtain *no trace* of electricity. Chemical action, therefore, appears to have nothing to do with the excitement of electricity by a current of steam."

On the other hand, Peltier takes an opposite view (*L'Institute*, August 7th, 1844); and for the following summary of his views we are indebted to the eminent experimentalist, Dr. Noad:—"Peltier does not adopt the theory that friction is the cause of the wonderful development of electricity in the hydro-electric machine; he refers it to chemical decomposition. Every chemical action produces an electric phenomenon; and every solution, however diluted it might be, being a chemical combination, it follows that, in the act of evaporation above a solution, the combined element, by separating, produces the converse chemical action, that of decomposition; and hence an electrical phenomenon with signs contrary to the act of combination. The reason why electrical phenomena are not manifested during slow evaporation, or even during the boiling of water under simple atmospheric pressure, is, according to Peltier, that the vapour is not separated with sufficient suddenness from the rest of the liquid to carry away and retain the electricity of the chemical action of its separation; the neutralisation by return being made with too great facility in the moist atmosphere touching the surface of the liquid. A boiler is but another means of obtaining vapour at high tension, as it suddenly separates from the liquid; but the form we are obliged to give it is very much opposed to the free liberation of electricity, so that we obtain but comparatively very small quantities of what is really produced. The quantities depend not only on the internal pressure, but also on the *jets* which oppose or facilitate the neutralisation or return. Hence it is that powerful locomotives have been seen to present but feeble electrical results, while a small boiler may give them on a considerable scale. When a saline solution is projected into a red-hot platina crucible, it becomes insulated from the vessel, and its evaporation goes on slowly, the temperature of the liquid never reaching the boiling-point of water. As, however, the concentration proceeds, particles of saline matter become deposited on the sides of the vessel, and establish partial contacts between the liquid and the metal: these particles of liquid are thus suddenly transformed into vapour, the tension of which is proportionate to the temperature at which it has been formed; and it is these vapours alone that preserve the electricity due to its passage from the liquid to the gaseous state. The higher the temperature of the capsule, the greater the quantity of electricity preserved: below 230° Peltier obtained no signs of electricity. When, in this experiment, pure water is substituted for the saline solution, no electricity can be obtained, because no contact takes place between the liquid and the metal until the temperature of the latter has descended to about 230°; the evaporation then goes on too slowly to place an insulating space between the vapour and the liquid; and the electric phenomenon is completed by returning to a state of neutralisation, by means of the conductibility of the column of vapour. To obtain electricity from high-pressure boilers, the conditions are—1st, an internal pressure of several atmospheres; 2nd, that the vapour shall be accompanied by a projection of water; and Peltier's view is, that the electricity is not brought out from the boiler by the escaping vapour, but that it arises from the vapour of the drops of water that are projected at a high temperature, a portion of which is immediately vaporised.

"Some interesting experiments are related by Peltier in illustration of his view. By elevating an electrometer immediately underneath the column of vapour, given off by a locomotive engine in motion, he found that the electrical signs were more considerable as the rapidity of the train increased; they diminished as the velocity diminished; and when the train was near stopping, all signs of electricity disappeared. This he explains by referring the electrical phenomena to the quick separation of the liquid and vapour at the moment of its formation; when the train was moving quickly, the column of vapour was rapidly broken up into particles; as the velocity diminished, the columns became more united, and there was, therefore, less electrical development. The more rare the globular vapour, the greater the sign of *positive* electricity; the electricity of an opaque column was, on the contrary, negative: it was noticed, also, that the condensation of the vapour on the ball of the electroscope, suddenly changed the electricity from positive to negative, the intermediate portions alternating from positive to negative, according to the velocity of the train, the quantity of the prevailing vapours, the rapidity of the evaporation, and the state of the sky."

Ingenious and elaborate as the preceding series of arguments may be, they certainly fail to prove, in any respect—except by inference of a logical, certainly not experimental, character—the "fact" that the electricity of the hydro-electric machine is due to chemical action; and the whole of the investigation is in striking contrast with that undertaken by Faraday, who, step by step, proved all that he advanced. At the conclusion of his remarks on the subject, in Series xviii., § 2,145, Faraday thus expresses himself:—"Finally, I may say that the cause of the evolution of electricity by the liberation of confined steam is not evaporation; and further, being I believe friction, it has no effect in producing, and is not connected with, the general electricity of the atmosphere; also, that, as far as I have been able to proceed, pure gases—that is, gases not mingled with solid or

liquid particles—do not excite electricity by friction against solid or liquid substances."

We have thus endeavoured to give an impartial view of the chief theories that have been advanced to account for the action of the voltaic pile or cell, pointing out the various bearings that each view has on the subject. Eminent men have been engaged on both sides of the question; and the controversy, in the end, has resulted in favour of the chemical theory. Faraday, in concluding his defence, or rather claim, in favour of the chemical theory, observes—"The contact theory assumes that a force which is able to overcome powerful resistance, *can arise out of nothing;* that, without any change in the acting matter, or the consumption of any generating force, a current can be produced, which can go on for ever against a constant resistance, or only be stopped, as in the voltaic trough, by the ruins which its exertions have heaped on its own course. The chemical theory, on the other hand, sets out with a power, the existence of which is *pre-proved;* and then follow its variations, rarely assuming anything which is not supported by some corresponding simple chemical fact. The contact theory sets out with an assumption, to which it adds others, as the cases require; until, at last, the contact force, instead of being the firm, unchangeable thing at first supposed by Volta, is as variable as chemical force itself. Were it otherwise than it is, and were the contact theory true, then the equality of cause and effect must be denied. Then would perpetual motion also be true; and it would not be difficult, upon the first given case of an electric current by contact alone, to produce an electro-magnetic arrangement, which, as to its principle, would go on producing mechanical effects for ever."

We have brought into discussion, under this head, what has been stated in respect to the chemical action of amalgams, as being the cause of the power of the frictional machine, and Peltier's view in respect to the hydro-electric machine, so that our readers may have a full general view of what has been said on the subject, and so get a comprehensive glance of its various bearings.

CHAPTER X.

THERMO-ELECTRICITY; OR THAT FORCE PRODUCED BY HEAT.

THE facts of thermo-electricity are conveniently arranged in succession to the preceding subjects of frictional and voltaic electricity; for the force, as induced by electric currents acting on adjacent wires by magneto-induction, etc., requires a previous study of the phenomena of magnetism.

In the preceding pages, attention has been called to the mutual production of electricity, heat, light, and magnetism. We have seen that, by friction of glass, etc., light, heat, magnetic and chemical phenomena are readily evolved. But by electricity evolved through chemical decomposition and affinity, all these phenomena are manifested in a still higher degree than by static electric agency. Many years ago, it was discovered that light had a magnetising power; or, at all events, that the rays of the sun were capable of exerting such an effect. On the other hand, a beam of light can be affected by the magnet; for the electric disruptive discharge, as produced between charcoal points, described at p. 239, *ante*, is at once acted on and deflected if a powerful magnet be presented to it. Some of the most interesting discoveries of Faraday, in connection with dia-magnetism, were made in reference to the action of magnetism on the rays of light; and which will subsequently be fully noticed.

A difference in temperature between two metals has the power of causing the production of an electric current, certainly much feebler than that produced by chemical action, yet evident and measurable. This fact, and the attendant phenomena, still more closely bind together the study of the effects of heat, light, &c., considering that, by the aid of heat, we can produce the remaining forces. It has long been known, again, that heat greatly affects the power of a magnetic bar of steel; and here we have another connecting tie with what have been somewhat erroneously termed the "imponderable agents," or, more correctly, the undulatory forces.

Many have been the speculations as to the nature of each and all of them. Formerly, it was supposed, in respect to heat, that two forces were concerned in its manifestation—namely, heat and cold, as two separate agents; reminding us of the dual character of electricity, as promulgated in the generally-received theory of Du Fay, that presumes the distinct existence of vitreous and resinous electricity. But this double theory of heat has long ago been discarded. Cold is now regarded simply as the result of the absence of sensible heat; and hence our present theory is, so far, analogous to the simple fluid theory of electricity proposed by Franklin—already discussed, in respect to its merits, with the double theory, frequently in the preceding pages.

Before entering on a description of the phenomena of thermo-electricity, it may be as well

to give some account of what constitutes *sensible* and *latent* heat; for on the abstraction of the latter, depends, in fact, the cause of the electrical phenomena generated by heat.

The term *sensible heat* is applied to the force when it can either be perceived by the senses, or be measured by suitable instruments. Thus, when the temperature of any body is raised, as in the act of boiling water, its sensible heat becomes increased. If a thermometer be plunged into the liquid, it will be noticed that the mercury or spirit in that instrument gradually rises until —if the water be tolerably pure, boiled in an open metal vessel at the level of the sea, and with the barometer standing at thirty inches—a temperature of 212° Fah., 100° Centigrade, or 80° Reaumur, be obtained. But it will be impossible, under *all* the preceding conditions, to raise the temperature of the water higher; for, as steam is produced, it carries off all the heat, in a *latent* state, that is communicated to the water, which, consequently, cannot acquire a higher temperature. If, however, the steam be collected, and passed through cold water, it will be found capable of heating, to a boiling temperature, upwards of *five times* as much water, by weight, as composes the steam so used.

From this, it is evident that the heat so carried from the water must become *latent*, or hidden; for if a thermometer be immersed in the steam, its sensible heat is not the fraction of a degree greater than that of the water from the surface of which it is produced. Again, if the boiling water be mixed with cold water, the mixture will attain a mean temperature between the two. But if the same weight of steam, at the same temperature, be passed through the cold water, it heats upwards of five times its weight of that liquid. Hence we conclude, that five times, at least, more of latent heat is carried off by the steam of boiling water than is evidenced by the sensible temperature of that liquid.

Daily life presents us with an infinite number of instances in which latent heat is converted into sensible heat. In the ordinary operation of lighting a fire, the ignited match applied to the wood and paper induces chemical action. The oxygen of the air combines with the carbon and hydrogen of the paper, wood, and coals; and this action spreading throughout the mass, evolves the *latent* heat previously in the fuel, producing that force, and light, in any desired quantity.

A very striking and impressive experiment, and one that convincingly teaches the nature and effects of the evolution of heat, is as follows: It will be seen that no ignited substance is employed to cause the first production of the heat. Let a small quantity—as a fluid ounce of bisulphide of carbon—dissolve as much as it will take up of phosphorus, previously freed from all external water by pressing it between the folds of bibulous paper; putting the phosphorus into a glass-stoppered bottle holding the bisulphide of carbon. If a little of this liquid be poured on to the wood and paper of a ready-laid fire, after the lapse of a few seconds the whole will burst into flame. The phosphorus is left, by the evaporation of the bisulphide, in a state of extremely minute division; and, as the oxygen of the atmosphere passes over its surface, rapid oxidation takes place. This induces combustion; and, consequently, from a cold liquid, and equally cold mass of fuel, intense ignition and combustion arise. It is scarcely needful to state, that the greatest possible care should be taken not to let the dissolved phosphorus fall on an object unintentionally, as its ignition will be almost sure to occur if the body contain any solid inflammable substance.

Here we have the remarkable case of a liquid, at ordinary temperatures, under favourable circumstances, producing an enormous amount of light and heat. Thousands of such instances might be adduced in connection with chemical phenomena; but the preceding will answer every purpose of showing the evolution of sensible heat from bodies previously containing it in a latent form.

It is necessary to remark, that thermo-electricity should not be confounded with that form of the force generated by sudden evaporation, as illustrated at p. 184, Fig. 98, *ante*; where the passage of liquid into vapour represents the divergence of the gold leaves of the electroscope: nor with the electricity of the hydro-electric machine, in which the force is caused by the friction of water (see *ante*, p. 185; and subsequently, in the discussion of the voltaic pile theories, at p. 257). In both these cases, little doubt can exist that mechanical circumstances are the sole exciting cause.

It is to Professor Seebeck, of Berlin, that we owe the discovery of the production of an electric current by the motive force of heat; and this effect was first illustrated by the result the heat-electric current produces on a horizontally-suspended magnetic needle. At p. 253, *ante*, Fig. 163, we have illustrated the method of diverging the needle by the current of a voltaic battery; and a somewhat similar arrangement is employed to show, in an elementary form, the phenomena of thermo-electricity,

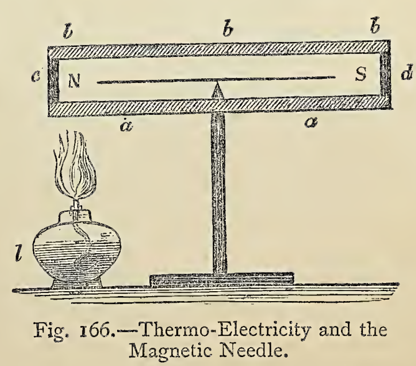


Fig. 166.—Thermo-Electricity and the Magnetic Needle.

except that, in the latter case, the battery forms part of the instrument.

In the preceding cut, a simple piece of apparatus is illustrated. *a a* is a rectangular bar of antimony; and *b b b* one of bismuth, soldered together at *c* and *d*. N S are respectively the north and south poles of a magnetic needle, suspended on a pivot horizontally, in the usual manner. If heat, as that of a spirit-lamp, *l*, be applied at *c*, whilst *d* is cooled by placing on it a little ice, or by dropping ether on it, an electric current is generated, which will deflect the needle precisely in the same manner as is effected by the voltaic current, illustrated at p. 252, *ante*. The sensitiveness of the needle is increased by rendering it *astatic*, in the manner already explained and illustrated at p. 253, *ante*.

The reason that bismuth and antimony are chosen for the construction of a thermo-electric arrangement, is, that they form the extremities of a series, positive and negative to each other, analogous to, but utterly different from, a series of metals taken in respect to their power of exciting a voltaic current. Thus, in the preceding pages, it has been frequently stated, that with the *same* exciting fluids, a cell of silver and zinc gives more electro-motive force than one of copper and zinc; again, that charcoal, platina, and passive iron, with zinc, either or all, afford a more powerful curent than one even of silver and zinc; so, practically, with zinc, and under precisely the same conditions, the power of a cell rises successively in order of the negative metals following; that is, zinc + copper, silver, gold, charcoal, or platina.

As just stated, the thermo-electric series is analogous, but different, and, for all ordinary metals, stands thus—

Bismuth
Nickel
Platinum
Palladium
Tin
Lead
Brass
Gold
Copper
Silver
Zinc
Carbon
Iron
Antimony.

In other words, bismuth is positive to nickel, whilst nickel is negative to bismuth; but as we descend the series, each metal becomes positive to all below it in the list, and negative to all above it; consequently, as bismuth is most positive, and antimony the most negative, they form the most powerful combination for thermo-electric purposes.

The direction of the current is from the heated end of the arrangement to that which is kept cool; and hence it is evident that heat is the exciting cause, so far as external manifestation affords evidence. Still further, the greater the difference of the temperature of the two extremities, the larger is the quantity of electricity afforded—another evidence that heat is the source of the power; or, more correctly, that, when the two extremities of the apparatus differ in temperature, then an electric current is established. Indeed, if one end of a thermo-electric battery be greatly cooled down, and the other be left at the ordinary temperature of the atmosphere, a current, but certainly a feeble one, is generated.

The arrangement that has been described, however, only affords a comparatively slight indication of thermo-electrie phenomena, and is quite inadequate to prove that the current thus generated is capable of producing magnetic, chemical, calorific, luminous, and even physiological effects; and we shall accordingly describe some arrangements that afford more evident results. Before doing so, however, the generality of the mutual action of the force of heat and electricity may be illustrated. In the preceding pages we have given numerous instances of the production of *heat* by electricity; but the following affords an instance of the production of *cold*.

If a bar of bismuth be soldered at right angles across one of antimony, and the positive current of a voltaic battery be passed by the wire so that it shall proceed from the bismuth to the antimony, to which the other wire is to be attached from the battery, a few drops of cold water may be frozen at the part of contact of the two crossed metals. This is a most singular and interesting fact. It proves that heat is absorbed at the junction of the two metals under such circumstances. By directing the current in a reverse way, heat can be generated; and thus the mutual relation of heat and electricity is strikingly illustrated.

Thermo-electric batteries have been variously constructed on the principles thus pointed out, bismuth and antimony being used for compound arrangements, as well as for a single one. Melloni and Nobili were amongst the first to produce them; and very valuable results to scientific research arose from the construction of such instruments; for, as will be subsequently apparent, the thermo-electric battery gives us an admirable instrument, to be employed in the study of radiant heat. In all forms of the thermo-electric battery that have been constructed, the metals used have been bismuth and antimony; and it is their arrangement in form that alone differs between each. In the following cut the metals are arranged in a mass of

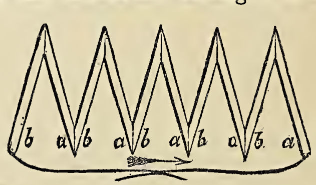


Fig. 167.—Thermo-Electric Battery.

cones, or in a V-like shape, their ends being soldered together at each point.

Nobili and Melloni constructed one, in which the metals are arranged somewhat in the form of the binding-back of a book, as shown in the

annexed cut; in which A represents the negative antimony, and B the positive bismuth. Commonly, they are now constructed by soldering, edge to edge, bars of the two metals, which are kept separate by thick paper, but otherwise brought as close together as is possible in reference to the efficiency of the pile. Professor Canning adopted a form resembling that of a wheel, in which the bars are inserted just like spokes, and soldered to each. Locke's battery consists of a number of the double bars placed vertically, their interstices being filled with plaster of Paris, and the extremities alone exposed. One end of the arrangement is then heated, by placing on it a metallic cover, whilst the other extremity is kept in ice; a wire from the last bismuth and antimony affording, as usual, a passage for the current. Besides these, are Dove's, Van der Voort's, Watkins', and others.

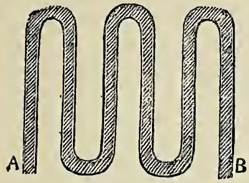


Fig. 168.
Thermo-Electric Battery.

The general effect of any of these forms of arrangements may be stated as simply identical with those of voltaic electricity, and, therefore, need not be detailed. Their application, however, in affording us a means of measuring radiant heat, and as, in part, explanatory of the electric currents of the earth, constantly circulating from east to west within the earth, and parallel to the magnetic equator, are matters of special interest, and which we must briefly allude to.

Melloni's arrangement is especially applicable to show the transmission of heat through divers media; and here it may be remarked, that heat, in the absence of light, is not easily transmitted through even transparent bodies; that is, so far as these permit the passage of light. An ordinary thermometer would be insensible to the passage of such rays; but a thermo-electric battery, if properly constructed, at once indicates their presence.

Nobili's thermo-electric battery, first employed for such a purpose, consisted of fifty pairs of antimony and bismuth bars, soldered together at their alternate ends, and represented in the centre of the following cut. At the

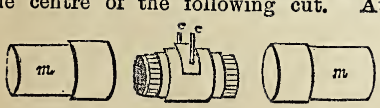


Fig. 169.—Nobili's Thermo-Battery.

extreme bismuth and antimony plates are two wires, *c c*, insulated by being fixed in an ivory collar; *m m* are two metallic sheaths, blackened internally and at the extremities, but polished in other parts. The rays of radiant heat impinging on one end of the apparatus, at once excites an electric current. The entire arrangement of the apparatus for thus measuring the amount of radiant heat by its electrical effects, is illustrated by the following engraving; in which *a* represents a non-luminous source of heat; *b* and *c*, screens, through which the heat-rays pass;

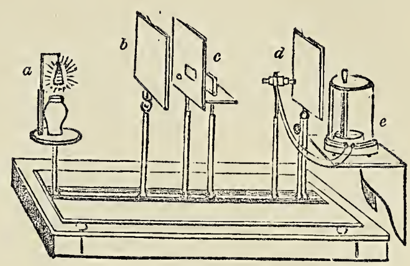


Fig. 170.

d, the thermo-electric battery; and *e*, a galvanometer, with a short circuit of thick wires, because the tension, or power, of overcoming resistance by the thermo-electric current is very slight. By such an arrangement, a variation in temperature, equal to $\frac{1}{5000}$th part of a degree Fah., may be measured, and the power of a body to transmit heat estimated.

This application of thermo-electricity has been of great importance in connection with the study of non-luminous heat-rays, and has opened out new fields of research; for, in experimental science, as in those in which optical powers of observation are involved, our attempts at investigation are frequently stopped through want of delicacy in the instruments we employ; and, therefore, we have to wait until some inventive power aids us by presenting new and improved forms of apparatus.

In reference to the second point of interest to which we have to draw attention—namely, the explanation of the cause of terrestrial electric currents—Ampère suggests, that the production of such currents is due to the heating effect on the earth, as derived from the solar rays; of course, the east becoming first under the solar influence, whilst a more westerly position is, for the time, destitute of the solar heat in the sun's absence. It hence follows that the earth may be a great thermo-electric battery, generating currents from east to west; that is, from the hot to the cold extreme, just as is represented in Fig. 166, p. 259, *ante*, that illustrates the first principles of thermo-electricity.

Knowing the existence of such currents, whatever may be their cause, it is by no means unlikely, that heat, in the manner above mentioned, may be influential in producing them; and we may assume, still further, the magnetism of the earth to be due to the passage of such currents round it; for, as it is evident from all knowledge we have of magnetism, that the earth is a huge magnet, and that, as shown at p. 80, an electric current influences a magnet, or can readily convert soft iron, as it circulates round it, into a powerful magnet—such conditions are precisely those that naturally exist in the earth, terrestrial currents passing at right angles to the magnetic meridian, and parallel to its equator.

In almost similar expressions, an able inves-

tigator of experimental science remarks as follows :—

"A consideration of the laws of thermo-electricity led to some most interesting conclusions. For example, it presented us with a probable explanation of the cause of terrestrial magnetic direction. That a freely-suspended magnet should tend to place itself in a line from north to south, was long a mystery so remote from the conceptions of philosophers, that no hope was entertained of arriving at its solution. At present we have a plausible explanation of the phenomenon. It has already been demonstrated that a suspended magnetic needle, free to move in any direction, places itself at right angles to a neighbouring electric current; hence, in order to explain the directive tendency of a magnet from north to south, it is only necessary to assume the existence of an electric current at right angles to it. Now the earth is warmed by the sun's rays in the direction of east to west; and a consequence of this heating must necessarily be the generation of an electric current in the same direction. A consideration of the relations subsisting between electric currents and magnetic force, will show that our globe should be magnetic in a line at right angles to the ecliptic. In point of fact, it is very nearly so; and, probably, would exactly coincide with that line, were there no secondary electric agencies in operation. This explanation is in accordance with Ampère's theory of magnetism; for the purpose of illustrating which, Mr. Barlow constructed an apparatus representing the supposed magnetic condition of our globe in miniature. His apparatus consisted of a hollow sphere of wood, in which electrical currents were made to circulate, similarly to the presumed direction of those in our own globe. By placing an astatic needle on various parts of the surface of the apparatus in question, it was found that all the phenomena of terrestrial magnetism were closely imitated."

For the following series of interesting facts we are indebted to Mr. Noad, as given in his *Manual of Electricity*. They are connected both with the subject of voltaic and thermo-electricity.

Generation of a Voltaic Current by Flame.—M. Hankel and M. Buff have published papers, showing, by the use of highly sensitive galvanometers, a current, apparently produced by flame, which passes from the upper to the lower part of the flame. Buff attributes this current to thermo-electricity: the flame being a conductor, and the two metals in contact with different parts of it, the thermo-current passes from the hotter to the cooler metal; and hence the result. Mr. Grove (*Notices of the Meetings of the Royal Institution*, February 3rd, 1854), in studying this subject, and without having then read the papers of Hankel and Buff, found the results so varying in ordinary flame, that he could come to no satisfactory conclusion: he was led to think, that as, in the flame of the blow-pipe, the direction or line of combustion is more definite than in ordinary flame, he might get more definite results. He experimented with the latter flame, and immediately got very distinct evidence of a current *not* due to thermo-electricity, as it could be made to conquer both the effect of the thermo-flame-current noticed by Buff, and of any thermo-current excited in the junction of the wires exterior to the flame.

"The current which Mr. Grove termed the current proper, moves from the root towards the point of the blow-pipe flame; the best points for placing the collecting spirals or plates of platinum being, for the one, a little above the root or base of the blue cone; and for the other, in the full yellow flame, a little beyond the apex of the blue cone. As the latter metal is much more heated than the former, the thermo-current is opposed to, and though it by no means destroys, it tends to weaken, the effect of the flame-current proper: if then this metal can be adventitiously cooled, we should have the two currents co-operating instead of conflicting; and so experiment proved; for by using a capsule of platinum filled with water, in the full flame, and a coil or sheet of platinum foil at the base, a very marked current resulted. By arranging a row of jets worked by a large bellows, a sheet of platinum foil, placed first over the roots of the flame, and a trough of platinum foil filled with water just beyond the points of the blue cones, the large galvanometer of the institution was deflected to 30° or 40°, the deflection being in the reverse direction upon reversing the connections respectively with the plate and trough. The same apparatus will also readily decompose iodide of potassium, iodine being evolved at the platinum point in connection with the trough." Mr. Grove ascribed these results to chemical action; "the platinum at the commencement of the action representing the zinc, which burns or combines with oxygen; that at the conclusion representing the platinum, or the points where chemical action concludes, and a tendency to reduction or deoxidation is manifested; the distinction being, that the generative chemical action, instead of taking place as in the ordinary battery only at the zinc surface, and being simply transmitted by the electrolyte, takes place throughout the intervening section of flame; and thus, within certain limits, the intensity of the electricity increases with the distance of the plates, instead of decreasing, as in the ordinary battery."

CHAPTER XI.

ELECTRO-METALLURGY; OR THE ART OF ELECTROTYPING, ELECTRO-PLATING, GILDING, AND DEPOSITING METALS GENERALLY.

USUALLY, in all applications of science, a long interval exists between the discovery of principles, laws, and facts, and their practical adaptation in the arts, manufactures, etc. We are slow to discover the useful, although we may be acquainted with that which will produce it. Three remarkable instances of this may be cited in the case of benzine, or benzol, first discovered by Faraday; paraffin; and aniline. Years elapsed before they were made of any commercial value; but, at the present day, they have assumed the highest importance, as objects of chemical manufacture, etc.

In a similar manner, the art of depositing metals by the action of the voltaic current, was a late development of previously-known principles. Nicholson, Carlisle, Davy, and others, had, thirty years before, studied the facts, and partly enunciated the laws, of electro-chemical decomposition; but it was not until the year 1839, that Spencer and Jacobi showed, that if a metal be deposited by electro-chemical action, it could be so employed to take the most perfect copies of the finest-executed medal, engraving, or other object; and, in fact, that the art might be employed in an almost infinite variety of ways for the purpose of copying nearly any solid object.

The discovery, however, when once made, excited such universal attention as to call a large number of workers into the field; and, in this respect, electrotyping was like its elder sister art, photography. Both appealed strongly to the refined exercise of our mental powers and taste; the eye was pleased by the results that each afforded; and hence, both within and without the pale of science, these arts became eminently popular.

We cannot forbear, very briefly, calling attention to the great value that so frequently arises from the pursuit of experimental research, that, for the moment, seemed to have no possible practical object. Little did Davy imagine, when he discovered the metallic bases of potassium, sodium, and the alkaline earths, that, in later years, his discovery should be enormously utilised in the abundant production of the now common metals, aluminium and magnesium. Still less, perhaps, could Nicholson and Carlisle have supposed that their discovery of the decomposition of water by voltaic action, should found an entirely new branch of manufacturing processes, now so largely followed in electro-plating, gilding, etc. Œrsted, who in 1819, first showed that an electrified wire deflected a magnetised needle, could not even have dreamed that, in forty years afterwards, his discovery should result in the construction of thousands of miles of terrestrial and submarine telegraphic systems; and that, by an expansion of that discovery, Liverpool and New York, London and the chief cities of Hindostan, would be placed in almost instant means of inter-communication. But by the gradual, and, at last, complete, application of the abstract facts discovered by those and other eminent philosophers, the wildest fancies of the poet or fiction writer have been reduced to dry, commonplace, every-day acts and facts. If we go still further back to the days of Galvani and Volta, we arrive at the apex of a cone of scientific light-rays that, in their expansion from their source, seem capable of an infinite extension.

In respect to the history of the art of electrotyping, we must accord the merit of discovery, so far as our country is concerned, to Mr. Thomas Spencer, of Liverpool; although, almost simultaneously, the celebrated Professor Jacobi, of St. Petersburg, announced that he had obtained results all but identical with those arrived at by Spencer. The latter gentleman thus describes the steps that led him to the discovery, in a paper read before the members of the Liverpool Polytechnic Institution, about the middle of 1839. He says—

"The members of the society will recollect, that on the first evening it met, I read a paper upon the production of metallic veins in the crust of the earth; and that, among other specimens of cupreous crystallisation which I produced on that occasion, I exhibited three coins—one wholly covered with metallic crystals, the others on one side only. It was used under the following circumstances:—When about to make the experiment, I had not a slip of copper at hand to form the negative end of my own arrangement; and, as a good substitute, I took a penny, and fastened it to one end of the wire, and put it in connection with a piece of zinc in the apparatus described—a Daniell's battery. Voltaic action took place, and the copper coin became covered with a deposition of metal in a crystalline form. But when about to make another experiment, and being desirous of using the piece of wire used in the first instance, I pulled it off from the coin to which it was attached. In doing this, a piece of the deposited copper came off with it; and on examining the under portion, I found it contained an exact mould [copy] of a part of the head and letters of the coin, as smooth and sharp as the original in which it was deposited."

Nothing can exceed, in plainness of description and precision of detail, this account of Mr. Spencer's discovery of the art of electrotyping. At the time it was first published, great sensation was created; and, subsequently, claims to priority of discovery, or attempts to diminish the novelty of it, by showing that the coating of a Daniell's battery *could* produce precisely the same result by the deposition of metallic copper, were made. The evident truthfulness of Mr. Spencer's relation of his method of discovering the art, however, will commend itself to our readers; especially if we bear in mind that all the early experiments that were made subsequently by others, were founded on Spencer's method of copying the impress of coins, medals, medallions, &c. We were amongst the earliest to repeat Spencer's experiments; and, despite the little that was then known of the art, succeeded in copying plaster medallions that were abundantly sold at the period, representing the bust, in relief, of his majesty William IV., who had died two years previously, but whose kingly popularity had not been then forgotten.

Early in May, 1839, it was announced, in the *Athenæum*, that Professor Jacobi had discovered a similar method to that of Spencer. It must *now* be borne in mind, however, that no electric telegraph existed, in that year, for the instantaneous communication of "news"—scientific, political, or otherwise—over Europe. Then the ordinary communication by post, through manuscript, or by printed papers, was exceedingly restricted, long in performance, and much rarer in adoption, than in our day. Hence we may justly conclude that Jacobi and Spencer—separated by a distance, practically, of upwards of two thousand miles—actually hit on the same method simultaneously.

Another claim was put forth, as the discoverer of the art of electrotyping, in favour of a Mr. Jordan, printer; who described, about the same period as that above mentioned, processes barely differing from those of Spencer and Jacobi. From whatever cause, just or unjust, Mr. Jordan's claims have never received general recognition; and, consequently, we shall pronounce no judgment on his merits, preferring merely to state that his name was associated with others, in 1839, as an independent discoverer of the art.

It is remarkable, that no great discovery in science has ever escaped the claims of a number of persons, each disputing priority. In 1867, the question was raised, at the meeting of the British Association, as to whether the laws of gravitation were not filched, in their exposition by Sir Isaac Newton, from Pascal; but it was subsequently proved, that the documents on which such pretensions were founded, turned out to be forgeries. It is sad that, after a lapse of nearly 200 years, not only the reputation as a philosopher, but even the honesty of a man, was called in question by, at first sight, most plausible grounds. In still later days—in fact, from the period of the discovery of the electrotype to about 1867—the most bitter controversy was waged between two eminent men as to which of them deserved the credit of the application of electricity as a telegraphic agent. For the credit of science, and that of the individuals, we forbear mentioning names; but our scientific readers will readily fill up the blank.

We cannot refrain here from congratulating the young beginners in science on the advantages possessed by them at the present day. When the arts of electrotyping and photography were first brought out, there was but one popular magazine devoted to the exposition of new scientific discoveries. Of course, we here except the *Philosophical Magazine*, and its contemporaries; the perusal of which was exclusively confined to scientific circles, and especially to members of philosophical societies. We remember but *one* popular work then extant on electricity, which gave a sufficient guide to the laws and pursuits of the science; and only one institution—the Polytechnic, in Regent Street, London—at which the general public could obtain, at a reasonable cost, any idea of what was going on in the scientific world. Now, thanks to the extension of a free press, the growing intelligence of the masses, cheapness of paper and postage, and other causes that we cannot stop to enumerate, the poorest mechanic or operative in the land, has, within certain limits, advantages equal to those afforded by our colleges or leading scientific societies. The stores or results of the labours of these have become common property; any one may become acquainted with all that is new in science within a week of the date of discovery; and if his interest be excited in the matter, an individual may gather the most complete details, that will enable him, in most cases, at little cost, to repeat the experiments, or attain the results arrived at by others.

Continuing a brief historical notice of the progress of the art of electrotyping, and chiefly from memory, we may remark, that the method of obtaining copies of works of art, such as coins, &c., was that of taking reverse moulds by means of fusible metal poured on to them. The moulds so obtained were then submitted to voltaic action, in a solution of sulphate of copper, when a copy was effected by the deposition of the latter metal on the surface of the mould. The deposit and mould were then separated, and the former produced an electrotype copy, identical, in all respects, with the original coin or medal. In many instances, however, inexperienced hands fell into serious difficulties. For example, if the surface of the original was perfectly clean, the fusible metal would adhere to it at times, and so the mould could not be separated from the coin, so that the latter would be irretrievably injured. In one case that came under our knowledge, a highly valuable engraved copper plate was thus rendered entirely useless, and the operator all but ruined. The next step, therefore, was to find some material that would afford a means of obtaining the reverse copy of a metallic original, and yet be unattended with the risks that the fusible metal, or a direct exposure to voltaic action, might produce.

In the early days of electrotyping, gutta-percha was quite unknown. The first material that was practically employed was white bees-wax. Others equally adaptable to obtain copies were proposed; but with all of them a difficulty arose. In each case, the materials, if not metallic, were non-conductors of electricity—at all events, of the force in the form of the voltaic current; and consequently, whilst affording excellent and accurate copies, still the surface was valueless and powerless in respect to its receiving a coating of copper, or any other metal, by electro-deposition.

At this juncture, the late Mr. Murray, long the friend of Davy and Faraday, and to whom we offer the grateful tribute of having been the subject of many kindnesses at his hands, discovered, that if a thin film of black-lead were rubbed over such non-conducting surfaces, they became sufficiently conducting to allow of the gradual spread of a film of copper by the agency of electro-deposition. Carbon in the form of railway coke, the lining of long-used gas retorts, black-lead or plumbago, box-wood charcoal, and even common coke, is, in each case, a conductor of electricity. Consequently, if good powdered black-lead be rubbed by a dry, soft brush on a wax, gutta-percha, or other such surface, they become sufficiently conducting to allow of the moulds made of such materials becoming surfaces fit for electro-deposition. The method of doing this will be minutely pointed out hereafter; as, for the present, we are merely tracing the progress of the art historically. Mr. Murray thus made a discovery only second in importance to that of the art itself; for his method is still universally adopted in electrotyping.

When the art of electrotyping was first practised, the mould was made to do duty as the negative plate of the battery, by what was called the single-cell apparatus. Thus, in the annexed cut, such an arrangement is represented. *z* is a zinc plate, first amalgamated by rubbing its surface over with acid-water and mercury, whereby local action is prevented; *w* is a wire connecting the zinc plate with the mould, *m*, to be copied; P is a porous pot, holding a mixture of one part of sulphuric acid, and ten of water, in which the zinc rests; whilst *g g* is a glass or porcelain vessel filled with a solution of sulphate of copper, to which a tenth part, in bulk, of sulphuric acid has been added. The process is extremely simple. The acid-water in the porous pot, P, acting on the zinc, *z*, produces an electric current that passes from the zinc through the liquids, to the mould, *m*. Now, by the chemical action that goes on, hydrogen would be evolved at the surface of *m*; but, meeting there with the oxide of copper contained in the copper salt, it decomposes the latter, precipitating metallic copper on the conducting surface of the mould. The electric current passes from *m*, by the wire *w*, to the zinc; and so a continuous deposition of the metal progresses so long as any sulphate of copper is contained in solution in the vessel, *g g*.

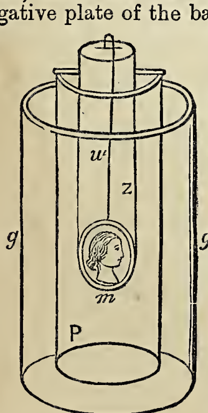


Fig. 171.

But this last remark requires qualification. Gradually, as the copper-salt solution becomes decomposed, its acid is set free. Its composition is that of an equivalent of copper, one of oxygen, and one of sulphuric acid. Consequently the copper disappears from the solution, whilst the acid increases in quantity. The liquid, when first made by dissolving the sulphate of copper in water, will have a deep blue colour; but when exhausted of copper, it will be quite colourless. As this exhaustion goes on, unless fresh crystals of the salt be kept constantly supplied, the quality of the metal thrown down on the mould deteriorates—it becomes hard, brittle, and crystalline, degenerating even into a brown or blackish-coloured powder, that has little or no tenacity, and would render a copper copy so produced utterly useless, either for attempted preservation or use in the arts.

Consequently, when Mr. Mason introduced what is called the battery process, by means of which the same solution could be used for an indefinite time, he effected an enormous improvement in the art. His method is that alone now employed. A voltaic battery is connected by wires, respectively, with a plate of metal to be dissolved away; and that is the electrode, or anode, of the negative plates of the battery; whilst the cathode, which receives the deposit, is connected with the zinc element of the battery. The anode and cathode are immersed in a separate trough, which contains a solution of the metal that has to be deposited; and, consequently, so long as the current passes, any loss that the liquid sustains of metal in solution, is at once replaced by the solution of the anode. The art has, therefore, by this ingenious arrangement, been rendered certain in its employment; whilst the results obtained may be controlled with mathematical precision.

This latter feature is one of high importance in the economical application of electrotyping. In respect to the deposition of copper, the waste of a pound or two becomes only a question of a few pence; but in the deposition of the precious metals, very opposite conditions prevail. Thus, a *grain* of gold, as deposited by voltaic electricity, is worth more than twopence; for pure gold that must be employed is worth that price in the market; and to that must be added the cost of bringing it into solution, depositing, and so on. But, by the simplest mechanical arrangements, the amount of any metal deposited on an object may be controlled to the extent of even a fraction of a grain whilst the operation proceeds, if the battery process be employed. The details of this will be eventually described minutely.

After the art became fully known, a large number of inventors entered the field; and, consequently, applications for patents for im-

proved processes became great in number. Mr. Parkes, of Birmingham, did great service in the invention of a method of rendering non-conducting surfaces conducting. He proposed that they should first be coated with a solution of phosphorus in bisulphide of carbon, and afterwards immersed in a solution of nitrate of silver. By this method the objects become coated with a thin film of metallic silver; and they are, consequently, highly conducting. The great difficulty experienced in the employment of black-lead, consists in the all but impossibility of introducing it into fine lines, without either blocking them up, or else failing to leave a polished surface where the brush is applied.

Mr. Smee, in his *Electro-Metallurgy*, was one of the first to enunciate the laws on which the art depended for successful pursuit. He published the above-mentioned work within a year or two of the discovery of the art; and although his views required tempering by subsequent experience, still he laid, if we may so say, the foundation of the science involved in electrotyping, or electro-metallurgy. Mr. Smee enunciates, as the result of his early researches, the following principles :—

"The laws regulating the reduction of all metals in different states, were first given in this work [his *Electro-Metallurgy*], as the result of my own discoveries. By these we can *throw down* gold, silver, platinum, palladium, copper, iron, and almost all other metals in three states—namely, as a black powder, as a crystalline deposit, or as a flexible plate. These laws appear to me at once to raise the isolated facts, known as the *electrotype*, into a science; and to add electro-metallurgy as an auxiliary to the noble arts of this country." He then detailed the primary laws as follows :—

"Law I.—The metals are invariably thrown down as a *black powder*, when the current of electricity is so strong, in relation to the strength of the solution, that hydrogen is evolved from the negative plate of the decomposition cell.

"Law II.—Every metal is thrown down in a crystalline [or crystal] state when there is no evolution of gas from the negative plate [the cathode], or no tendency thereto.

"Law III.—Metals are reduced in the reguline [that is, in the true metallic condition] state when the quantity of electricity, in relation to the strength of the solution, is insufficient to cause the production [evolution] of hydrogen at the negative plate [the cathode] in the decomposition trough; and yet the quantity of electricity very nearly suffices to induce that phenomenon."

At this early stage of the history of the art, it is therefore evident that considerable progress had been made in studying and defining its laws; and, whatever modification the preceding exposition of them requires, still to Mr. Smee is due the first attempt at obtaining anything like precision of result. The popularity of the art of electrotyping was greatly increased by the publication of a cheap manual, written by the celebrated electrician, Mr. Walker, and published by Knight and Sons, of Foster Lane, Cheapside, London. This little work did service to the art. Precise, clear, and instructive in detail, it placed electrotyping in the hands of the masses, and tended greatly to assist in its development and progress.

Mr. Smee, perhaps, claims too much credit for the originality of some of his "discoveries." In the first place, even Spencer, Jacobi, and Jordan were anticipated, in respect to date, by others. Thus, in June, 1836, February, 1837, December, 1837, and July, 1838, patents were taken out, by either Messrs. G. R. or H. Elkington, for gilding copper, brass, and other metals; for gilding metals, and coating them with platinum, to protect their surface from oxidation; for gilding and silvering certain metals; and for coating and colouring certain metals. All of these methods were connected with electro-deposition by the processes proposed to be employed; and hence "electro-metallurgy, as an auxiliary to the noble arts of this country," had already been added before the publication of Mr. Smee's work. Again, Mr. Spencer, in the paper by which he first published his discovery, says—"I discovered that the solidity of the metallic deposition depended entirely on the weakness or intensity of the electro-chemical action, which I knew I had in my power to regulate at pleasure, by the thickness of the intervening wall of plaster of Paris, and by the coarseness or fineness of the material. I made three similar experiments, altering the texture and thickness each time, by which I ascertained that, if the partitions [porous pots] were *thin* and *coarse*, the metallic depositions proceeded with great rapidity, but the crystals were friable, and easily separated. On the other hand, if I made them thicker, and of a little finer material, the action was slower, but the metallic deposition was as solid and ductile as copper formed by the usual methods. Indeed, when the action was exceedingly slow, I have had a metallic deposition much harder than common sheet copper, but more brittle."

It is also evident that Mr. Spencer had attained a clear knowledge of the cause of electro-deposition; for he remarks—

"If we dip a piece of clean iron into a fluid containing a salt of copper in solution, and let it remain for a few minutes, it will be found to have received a coating of pure copper. If the iron, when first immersed, become *at once* thoroughly coated with the cupreous deposit, and this not dependent on any oxidation on its part, a solid but excessively thin metallic coating would be the result; and the piece of iron thus cased would act precisely as a piece of copper under similar circumstances, which, I need hardly say, would have no further action on the solution. But such not being the result, let us see what really takes place. No sooner is the iron immersed in the cupreous solution than *oxidation* takes place on portions of *its* surface. This is the primary action; the secondary being the *deoxidation* of the copper held in solution. This, when set free, at once obeys the laws of electric affinity, and, whilst under *electrical influence*, attaches itself to the nearest metallic

surface. The iron, being only partially oxidised, presents to the copper a surface covered with metallic points, and to these it attaches itself; but the oxidising process continues *still going forward* in the interstitial spaces that have *not* been covered with copper. But as this proceeds, the prominent points get undermined, and, falling to the bottom, expose fresh surfaces again to be deposited upon, so long as there is a piece of *metallic* iron left. The primary action in this, and in most other instances of electro-chemical decomposition, is caused by the decomposition of water, the oxygen of which combines with the iron; the secondary action being induced by the nascent hydrogen, which separates the copper in a pure state from the acid, or compound salt radical, with which it is in combination. We thus see that iron does precipitate copper in the *metallic* state, and the phenomenon is electrical."

We have thus given an outline of the early history of the art of electrotyping; from which it will be seen that, at its commencement, it engaged successfully the attention of both theoretical and practical men, and, consequently, soon went on to its present state of perfection.

We next proceed to investigate the various conditions on which the successful pursuit of electro-metallurgy depends. These include the chemical electrical, heat, mechanical, and mathematical. All these are essential, and must, consequently, be carefully studied in their details; for a full knowledge of them enables us to proceed with certainty in the practical operations of the art. First in order are the—

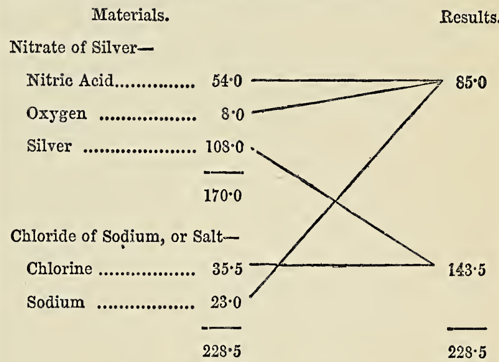
Chemical Conditions of Electro-Metallic Deposition.

It is an axiom—we might also say even a postulate—that the composition of every compound substance is universally the same, not only in its nature, but also in its mathematical relations. If we gather water from the greatest height in the atmosphere or from the sea, provided we free the water from all extraneous matter, its composition is invariable: nine grains of the liquid—or it may be ounces, pounds, hundredweights, or tons—always consist of one part, by weight, of hydrogen united with eight parts, by weight, of oxygen. What is true in respect to water is equally so in regard to all other compound bodies. Take, for example, common salt. No matter whence its source—say human tears, the salt beds of Cheshire or Poland, the ocean or the Dead Sea, the pond, well, or river—still its constitution is uniform; 35·5 parts of chlorine being united with 23 parts of the metal sodium to form 58·5, or 58½ parts of our pure table salt.

In practical chemistry all our progress depends on this fact. It would be impossible to make a correct analysis of any body if this law were not universally upheld. Supposing, for example, in making a silver solution for electro-plating purposes, we determined the purity of the nitrate of silver in the following manner. Taking 170 grains of the nitrate, if absolutely pure, we should expect its invariable constitution to be as follows: namely, of—

Silver	108 grains.
Oxygen	8 ,,
Nitric acid	54 ,,
	170 ,,

If, on adding to this 58·5 grains of pure common salt, we did not obtain 143·5 grains of chloride of silver, we should conclude that the nitrate had been adulterated; for the effect of the addition of chloride of sodium to nitrate of silver (both being pure) is as follows:—



But if a less amount of precipitate of chloride of silver than 143·5 grains be obtained by testing 170 grains, it is very evident that the nitrate must be impure; and thus, as in all cases of chemical analysis, we depend on the precision of combination that attends all chemical composition and decomposition, whether that take place by ordinary affinity, or under the influence of the electrical current.

It has hence arisen that the practical chemist has assigned to all bodies, elementary or compound in their nature, certain mathematical values that denote their ratio of combination. Not that we consider even our present advanced state of knowledge, in this respect, completely accurate. Far from that; there is every reason to believe many errors to exist; but, despite the number of these, our *known* and *proved accurate* results far outweigh the real or possibly erroneous.

The doctrine and facts of chemical equivalents, or combining proportions, being constant for the same substance under all circumstances, is a matter of the highest economic importance in the art of electro-metallurgy. To the practical man it is a question of commercial existence; for if he do not adhere rigidly to the teachings of such facts and laws, in respect to the quantity and intensity of the battery power he uses; to the amount of chemicals he employs in making his solutions; and to other allied matters that it is not necessary we should here name, his business cannot fail to bring *him* to failure. It is characteristic of the art of electro-metallurgy, that it may be carried on, and is, founded on data all but of absolute precision. As we have just shown, he that makes or buys 170 pounds of

nitrate of silver, *ought* to have in it 108 pounds of pure silver; and, moreover, the certainty of chemical analysis in this case is so great, that a man must be either mad, foolish, or reckless, who does not control his purchases by chemical analysis. Far different is it in many other branches of trade. If a manufacturer of cotton, wool, hemp, silk, &c., goes into the market to purchase, he sees either an average sample or the bulk. But, no matter how experienced he may be, it is impossible for him to form an accurate judgment of the quality of the goods before him, simply because the textile products of animal and vegetable life are never uniform, varying, as they do, from the exterior influences of climate, weather, temperature, &c., &c. But in the case of nearly every chemical compound produced for the purpose of the arts or manufactures, the purchase, if made of an inferior or impure article, can be adjusted, in regard to value, almost exactly. Hence, as already pointed out, the great importance of a knowledge of the combining proportions of bodies, as indicating their commercial value for electro-metallurgical processes.

In respect to compounds, we have already shown that their individual combining proportion is always a sum of those of their elementary or simple constituents; by which we mean, such bodies that have hitherto resisted all our attempts to reduce them into simpler forms than those with which we are acquainted as being their purest condition. Thus, in the preceding examples, silver, chlorine, sodium, and oxygen are each an elementary body; whilst nitric acid, composed of nitrogen and oxygen; chloride of sodium, composed of chlorine and sodium; and oxide of silver, composed of oxygen and silver, are compounds.

The total number of elementary bodies now estimated as such, and that have resisted all our attempts to render them still more simple in their nature, does not amount to seventy. The largest proportion is constituted of metallic bodies; yet comparatively few of these become the subjects of the operations of the electro-metallurgist, so far as deposition in the solid form is concerned. But in the chemical operations of the electrotyper, a much larger number become accessories; for he has to produce, by their action on other bodies, the solutions, &c., he has to employ.

To illustrate this, we will give an example or two. In depositing copper, it is necessary to employ a solution of sulphate of copper. This is composed of metallic copper, oxygen, and sulphur; and when dissolved in water, hydrogen and oxygen are additionally present. Of a much more complicated nature are the substances or solutions in electro-plating and gilding. The metals are, respectively, silver and gold, held in solution by cyanogen, a compound of carbon and nitrogen, and incidentally combined as a double salt with potassium. But the oxides of gold and silver are obtained by the action of various bodies on the salts preparatory to the production of the cyanide solutions. Thus the oxide of silver is produced by adding an alkali or lime, in a caustic but dissolved state, to a solution of nitrate of silver. Although, in the instances named, the final consequences of the operations of the electro-metallurgist are simply the deposition of copper, silver, and gold in the metallic condition, still other substances are accessory to those results. Indeed, we might greatly extend the list if we include washing, stripping, and other solutions, conducting solids and liquids *cum multis aliis.*

It will, therefore, at once be evident that a knowledge of the combining proportions of bodies should be attained by the practical man. We shall, accordingly, first give a table indicating those of the elementary bodies; and, afterwards, of some of the chief compounds employed in electro-metallurgy.

We may, however, first briefly state, that, as a matter of convenience, it has long been determined by chemists to assign certain symbols, as designative, not only of elementary bodies, but also of compounds. Such a method not only saves time and space, but, by the modern plan, simultaneously indicates the component parts of a body, and the proportion in which they combine. We will take, for example, the constitution of nitrate of silver. To explain it in writing, we have to say, that *one equivalent of silver* united to *one of oxygen*, and the two combined with *one of nitric acid* (which is composed of five equivalents of oxygen united to one of nitrogen), afford an equivalent of the nitrate of silver salt. But all this circumlocution is saved if we adopt the symbol method. Adopting Ag, an abbreviation of the Latin name of silver; O, an abbreviation of oxygen; N, an abbreviation for nitrogen, we can represent the constitution of the salt as—

$$AgO, NO_5;$$

or,

Ag,	equals one of silver		=	108
O	,, ,,	oxygen	=	8
N	,, ,,	nitrogen	=	14
O_5	,,	five of oxygen 5×8	=	40
				170

Thus, in the last formula, we gather precisely the same results, as descriptive of the constitution of the nitrate, as were previously given at p. 267, *ante*; but by the symbolical formula, we have a ready means of expressing the constitution of any body, that instantly gives an idea of its composition.

In the following table, the names of the elementary bodies, their symbols, their combining proportions under the hydrogen scale, as universally adopted in this country, and, under the oxygen scale, as preferred abroad, are given. The ratio subsisting between the two is as 1· to $12\frac{1}{2}$, so they are readily convertible. As a matter of convenience, the practical man will find it desirable to get off, by heart, the chemical equivalents of all the bodies that are marked thus (*) in the following table. He will thereby save the necessity of constant reference, and speedily acquire a knowledge of the mathematical value of the combining proportions of the substances he requires most in use, with their symbols.

Table of the Symbols and Equivalents of the Chief Elementary Bodies.

Name.	Symbol.	Equi. H = 1·00.	Equi. O = 100·0.
Aluminium	Al	13·7	171·25
Antimony	Sb	129·0	1612·50
Arsenic	As	75·0	937·50
Barium	Ba	68·5	856·25
Beryllium, or Glucinum	Be	6·9	86·25
Bismuth	Bi	213·0	2662·50
Boron	Bo	10·9	136·25
Bromine	Br	80·0	1000·00
Cadmium	Cd	56·0	700·00
*Calcium	Ca	20·0	250·00
*Carbon	C	6·0	75·00
Cerium	Ce	47·0	587·50
*Chlorine	Cl	35·5	443·75
Chromium	Cr	26·7	333·75
Cobalt	Co	29·5	368·75
Cœsium	Cs	133·0	1662·5
*Copper	Cu	31·7	396·25
Didymium	Dy	50·0	625·00
Erbium	Er		
Fluorine	F	19·0	237·50
*Gold (Aurum)	Au	197·0	2462·50
*HYDROGEN	H	1·0	12·50
Ilmenium	Il		
Indium			
Iodine	I	127·0	1587·50
Iridium	Ir	99·0	1237·50
*Iron	Fe	28·0	350·00
Lanthanum	Ln	47·0	587·50
*Lead	Pb	103·7	1296·25
Lithium	L	6·5	81·25
Magnesium	Mg	12·0	150·00
Manganese	Mn	27·6	345·00
*Mercury	Hg	100·0	1250·00
Molybdenum	Mo	46·0	575·00
Nickel	Ni	29·6	370·00
Niobium	Nb	48·8	610·00
*Nitrogen	N	14·0	175·00
Norium	No		
Osmium	Os	99·6	1245·00
*OXYGEN	O	8·0	100·00
Palladium	Pd	53·3	666·25
Pelopium	Pe		
*Phosphorus	P	31·0	387·50
*Platinum	Pt	98·7	1233·75
*Potassium	K	39·0	487·50
Rhodium	R	52·2	652·50
Rubidium	Rb	85·36	1067·00
Ruthenium	Ru	52·2	652·50
Selenium	Se	39·5	493·75
Silicium	Si	21·3	266·25
*Silver	Ag	108·0	1350·00
*Sodium	Na	23·0	287·50
Strontium	Sr	43·8	547·50
*Sulphur	S	16·0	200·00
Tantalum	Ta	184·0	2300·00
Tellurium	Te	64·2	802·50
Terbium	Tb		
Thallium	Tl	203·0	2537·5
Thorinum	Th	59·6	745·00
*Tin	Sn	58·0	725·00
Titanium	Ti	25·0	312·50
Tungsten	W	92·0	1150·00
Uranium	U	60·0	750·00
Vanadium	V	68·6	857·50
Yttrium	Y	32·0	400·00
*Zinc	Zn	32·6	407·50
Zirconium	Zr	33·6	420·00

The use of the preceding table will be apparent from the following illustration. Supposing that the operator requires to precipitate oxide of silver by lime, for the purpose of making a cyanide solution. We have already shown that an equivalent of nitrate of silver is equal to 170. By referring to the preceding table, it will be found that pure *caustic lime*, being an oxide of the metal calcium, is composed of the following elementary bodies, in the proportions named, to form one equivalent of lime: viz.—

Calcium	20
Oxygen	8
	28

Therefore, 28 parts of lime precipitate all the oxide of silver in 170 grains of the nitrate.

We may, however, become still more practical in our illustration. Supposing, for example, it were desired to know how much lime would be required to precipitate the oxide of silver from an ounce of the nitrate. It is self-evident that the proportion of an equivalent of nitrate—170 grains—to the number of grains in an ounce troy, or 480, is as 28, the equivalent of lime, is to the required quantity of lime; or, making a rule-of-three sum, we have—

$$170 : 480 :: 28 \text{ is to } x.$$

x representing the required portion of lime.

Reducing this to its arithmetical value, we have—

$$\frac{480 \times 28}{170} = 79\tfrac{1}{17} \text{ grains.}$$

Or a still simpler method, although at first not so obvious, arises from the fact that the equivalent (28) of lime is about the sixth part of 170, or that of nitrate of silver; so, therefore, if we divide $\frac{480}{6} = 80$, we arrive at nearly the same result.

It is evident, therefore, that a careful study and use of the preceding table is of the utmost value to the practical man, as a matter of preventing unnecessary waste. When, however, we enter into the discussion of what are called *electro*-chemical equivalents, it will be found that, in controlling the size and number of batteries, the same table has an equal and indispensable value in the prevention of waste, and the reduction of results to an absolute certainty, whether as regards the use of material, or employment of battery power.

Having thus explained the use of symbols, equivalent, or combining proportions, &c., we shall next give a table of the composition and equivalents of some of the chief compounds employed in electro-metallurgy.

Table of the Symbols and Equivalents of several Compounds.

Ammonia, Sesquicarbonate, $2\,NH_3\ 3\,CO_2\ 2\,HO = 118{\cdot}0$.
Carbonic Acid, $CO_2 = 22$.
Chloride of Sodium, or common salt, $Na\,Cl = 58{\cdot}5$.
Copper, Black, or Protoxide of, $Cu\,O = 39{\cdot}7$.
Copper, Sesquicyanide of, $Cu_3\,Cy_2 = 147{\cdot}1$.
Copper, Sulphate of, blue vitriol, bluestone, or Roman vitriol, $Cu\,O,\ SO_3\ 5\,HO = 124{\cdot}7$.
Cyanogen, Cy, or $NC_2 = 26{\cdot}0$.
Gold, Cyanide of, $Au\,Cy = 223{\cdot}0$.
Gold, Oxide of, $Au\,O = 205{\cdot}0$.
Gold, Terchloride of, $Au\,Cl_3 = 303{\cdot}5$.
Hydrochloric Acid, also called Muriatic Acid, or Spirits of Salts. Specific gravity, 1·21, $H\,Cl + 6\,HO = 90{\cdot}5$.
Iron, Sesquioxide of, Crocus, or Colcothar, $Fe_2\,O_3 = 80$.
Iron, Sulphate of, copperas, or green vitriol, $Fe\,O,\ SO_3\ 7\,HO = 139$.
Lime, Caustic, $Ca\,O = 28{\cdot}0$.
Magnesia, Calcined, $Mg\,O = 20$.
Magnesia, Carbonate $= Mg\,O,\ CO_2\ HO = 51{\cdot}0$.
Mercury, Cyanide of, $Hg\,Cy = 126{\cdot}0$.
Nitric Acid, specific gravity, 1·52, $NO_5 + 2\,HO = 72{\cdot}0$.
Platinum, Bichloride of, $Pt\,Cl_2 = 169{\cdot}7$.
Potash, Crystallised Carbonate, $KO\ CO_2\ HO = 78$.
Potash, fused, caustic, or hydrate, $KO\ HO = 56$.
Potassium, Cyanide of, $K\,Cy = 65{\cdot}0$.
Sal-ammoniac, or Chloride of Ammonium, $NH_3\ H\,Cl = 53{\cdot}5$.
Salt, common (see Chloride of Sodium).
Silver, Chloride of, $Ag\,Cl$, 143·5.
Silver, Cyanide of, $Ag\,Cy = 134$.
Silver, Nitrate of, $Ag\,NO_5 = 170{\cdot}0$.
Silver, Oxide of, $Ag\,O$, 116·0.
Soda, Carbonate, common washing soda, $Na\,O,\ CO_2\ 10\,HO = 143{\cdot}0$.
Sulphuric Acid, $SO_3 = 40$; but if hydrated, that is, as in the strongest commercial acid $= 49$. Specific gravity, 1·848.
Water, $HO = 9{\cdot}0$.
Zinc, Cyanide of, $Zn\,Cy = 58{\cdot}6$.
Zinc, Oxide of, $Zn\,O = 40{\cdot}6$.
Zinc, Sulphate of, in crystals, $Zn\,O,\ SO_3\ 7\,HO = 143{\cdot}6$; also called *White Vitriol.*

The preceding table contains the composition of all the most important chemicals employed in electro-metallurgy. We may add, by way of further explanation, that the large figures *preceding* a symbol multiply that symbol; as, for example, in sulphate of iron, there are 7 equivalents of water, or 7 HO. The small figures at the foot of a letter or symbol, only multiply the one element; as, in sulphuric acid, SO_3 signifies 1 equivalent of sulphur with 3 of oxygen; in nitric acid, NO_5, 1 of nitrogen united to 5 of oxygen; and so on.

The office of nearly all the foregoing named chemicals, is that of producing solutions capable, directly or indirectly, of undergoing electrical decomposition, or electrolysis. The latter term, literally, signifies "to set free by electric agency;" and, categorically, expresses the phenomena of decomposition as effected by the current.

When we detail the preparation of the best solutions to be employed in obtaining a metallic deposit, it will be found that each metal is best thrown down from a solution specific to itself. Thus a solution of sulphate of copper is best for the deposition of that metal. In regard to silver and gold, a solution of their cyanides in one of excess of cyanide of potassium, is much preferable to any other. Nothing is of greater importance in electro-metallurgy than ready solubility; because, as the agent set free by electricity is intended to dissolve the substance of the anode, and convey it thence in a soluble state for deposition on the cathode, or object to be coated, it is evident that the more readily such a solution is effected, *cæteris paribus*, the more quickly will the deposit of metal be carried on. Illustrative of this fact, we shall only, for the present, state that an increase of tempe-

rature almost invariably causes more rapid deposition, because it greatly facilitates solution; and, with but trifling exceptions, all bodies increase in solubility as the temperature of the dissolving solution increases. We could name instances in which five or ten times as much of some solids are dissolved at a boiling temperature, than at an ordinary one.

Connected with this subject, it may be added that, as the temperature of a solution decreases below certain limits, the electrolytic action is diminished, and, at last, entirely ceases, simply because solution ceases to be effected. For example, in summer-time electrotyping can be carried on with ease; whereas, in winter, unless the temperature be kept up to about 60° Fah., the action becomes feeble, and the deposited metal is of bad quality—a circumstance that still further shows the necessity of a careful watching of temperature. It is desirable, in fact, that the room in which electrotyping is carried on, should be kept, as near as possible, of an even temperature during the whole year—not only for the reasons already urged, but also for the following.

If, in a decomposing trough, the liquids be of unequal temperature—that is, the top warmer than the bottom of the liquid in any trough—deposition will go on more rapidly in the former condition than in the latter, and, consequently, the surface will be of uneven thickness. In making copper masses by electro-metallurgy, this unevenness, if the weight be great, may cause fracture. If a copy be made from an engraved plate, the "electro" will not stand the mechanical action of the press; and if the object be an electro to be used for type-press printing, the uneven portions of its surface will be soon destroyed. Hence the great importance of solubility, and consequently of temperature, in electro-metallurgical operations. As a last illustration, it may be named that, whilst chloride of silver is a non-conductor of the current when cold and solid, it at once becomes a conductor on being fused, and simultaneously undergoes decomposition. The influence of conduction on electrolysis will be subsequently examined when we have to treat on the *Electric Conditions* of the art.

A few words of advice in reference to the quality and purity of the chemicals employed in electro-metallurgy, may be of considerable service to the practical man; because proper precautions being taken in this respect, may save loss of money and time, besides preventing uncertainty and disappointment.

Water is certainly the most important of all the materials of the electrotyper, because it is the only available fluid that can be employed in his operations. The best kinds that he can employ are distilled, rain, river, and pond—the first being the best, as being all but pure, and the last the most inferior. Rarely should well water be employed, for it generally contains large quantities of earthy salts. If sulphate of copper, nitrate of silver, or acetate of lead be dissolved in any but distilled water, precipitates will be observed, that indicate, by their quantity, the amount of loss that is sustained; whilst the same salts, dissolved in distilled water, afford a perfectly clear solution.

To the practical man, the simplest test he can apply to examine the hardness of water is as follows:—Dissolve, in good spirits of wine, a little of the best curd soap, aiding the solution by placing the vessel holding them in another of hot water. The solution being effected, may be transferred to a stoppered bottle for use.

If a wine-glassful each of distilled, rain, river, and well waters be then ranged side by side, and a drop or two of the soap solution be added to each, and stirred up, the distilled water will show no change; perhaps the rain-water may become slightly turbid; the river water will take, under all ordinary circumstances, the appearance of weak milk and water; whilst the well water will become white and opaque. Each, therefore, successively shows increasing impurities; in the latter case indicating that the well water is quite unfit for electro-metallurgical operations.

The preceding method of testing water is sufficient for all practical purposes. But a more exact method is as follows:—If a portion of the water under examination be boiled to dryness, it will deposit nearly all its earthy salts, generally consisting of carbonate and sulphate of lime. If this deposit be then acted on by distilled water, in less quantity, in bulk, than the water first used, the soluble salts will be removed. Sulphates may be tested for by the addition of a solution of chloride of barium to a little of the solution in a glass, when all sulphuric acid will be precipitated as a sulphate of baryta. Chlorides may be detected by adding to another portion of the solution one of nitrate of silver, when chlorine will be precipitated as chloride of silver. Thus the chief common impurities of water obtained from rivers and other earth surfaces, or wells—viz., sulphate and carbonate of lime, sulphates of soda, potass, or magnesia, chlorides of potassium, sodium, &c., and oxide of iron—may be detected. The latter is more satisfactorily tested for by boiling a little of the water with nitric acid, and then adding a little solution of yellow prussiate of potass, when, if iron be present in any notable or important quantity, it will be immediately detected by producing a blue colour.

Few persons but those practically acquainted with chemistry, are aware of the quantity of mineral substances thus contained in some water. Many years ago, when engaged in chemical manufactures, the supply for our two 30-horse boilers was obtained from a well sunk in the sand over the London clay. On the first Monday in each month the boilers were always swept out; and never less than sufficient solid matter to fill a one-horse cart was removed—in weight exceeding one ton. Two other remarkable instances have also occurred within our own personal knowledge—in either case the parties getting their water from mountain limestone strata. In both instances, despite every attempt to prosecute the business successfully, a hidden cause militated against them; and it

was not until, by the aid of chemistry, each person was taught the impurities of the water were the offending causes, that a remedy was adopted. The cases were those of a bleacher and a paper manufacturer, in parts of England at considerable distance from each other.

From all these facts and considerations, it will be evident that the purer the water, the better fitted is it for the purposes of electro-metallurgy ; and if the operations be conducted with the precious metals, distilled water should be employed if possible. If a steam boiler be on the premises, nothing is easier than to have a copper tube, tinned inside, turned into the form of a worm, and placed in a vessel. One end of the worm should be connected by a tap with the boiler. The vessel containing the worm should be kept constantly filled with cold water. As the steam passes through the copper worm, it becomes condensed, and trickles away from the other end as distilled water, which may be collected for use. Lead or iron pipe should not be used to construct the worm, because they are both indirectly soluble in pure water, by contact of the carbonic acid of the atmosphere with the point of junction of the distilled water and the metals.

Rain-water, if collected near towns, may contain sulphuric acid, sulphate of ammonia, ammonia or its carbonate, or both ; and, occasionally, a minute quantity of nitric acid. If collected within a few miles of the sea-shore, and a strong wind be blowing inland, common salt and various sea-salts may be also present in considerable quantities. Hence the purity of rain-water depends on accidental circumstances. In using it, therefore, it should only be collected for electro-metallurgical processes when the direction of the wind is such that none of the above-named influences might tend to produce the results just pointed out.

Next to distilled and rain-water, the last and least complete method of obtaining soft water, is that of boiling river water before use. By doing this, all the carbonate of lime and oxide of iron are deposited as solids, forming the ordinary "fur" of the kettle. The carbonic acid is driven off, and only the soluble salts left, that can be detected by methods already pointed out at p. 271, *ante*.

Sulphuric Acid, or *Oil of Vitriol.*—This acid is the mainstay of electro-metallurgical operations, both for battery excitation, next the zinc, and in making some solutions. Generally speaking, that purchased of any eminent maker is sufficiently pure for all ordinary purposes. It has a specific gravity of not less than 1·845 ; that is, a vessel holding exactly 1,000 grains of distilled water at a temperature of 60°, should weigh 1,845 grains (exclusively, of course, in both cases, of the weight of the bottle). Whatever less than this the bulk of acid weighs, indicates a diminished strength. Two impurities chiefly occur in sulphuric acid. If it have been removed at too great a strength from the leaden chambers, it will have dissolved a portion of lead. This may easily be detected by adding water to dilute the acid. The sulphate of lead is insoluble in water ; and, if present in the acid, will fall down as a white precipitate.

The other impurity is of vital importance : we refer to the presence of nitric acid. This is occasioned by the use of nitric acid to afford oxygen to the sulphur during the manufacture of the sulphuric acid. We have seen specimens of the latter so impure, although nominally cheap, that, by the smell, it scarcely differed from nitric or "nitrous" acid. An exciting solution used on the zinc side of a battery made of such an acid, would be ruinous to the plates, as amalgamation does not in the least prevent the action of nitric acid on them. Hence to use such an acid would be folly in the extreme, and would, probably, lead to the use of three or four times as much zinc as would be required for any special deposition. It is evident, therefore, that neglect in this respect, if copper be deposited, may double the cost of that metal, zinc being generally one-fourth of its price in the sheet state. Bankruptcy, rather than the bank, would be the result of such operations.

Although any specimen of sulphuric acid may not smell of nitric acid, still the latter may be present : it may be detected as follows :—Procure a little Saxon blue, which is a solution of indigo in strong sulphuric acid, and may be obtained at the dye-house, or drysalter's ; put a few drops of this into a Florence flask, or test tube, with some of the suspected acid and a little water, and boil for a short time. If the colour of the whole remain, the tested acid is sufficiently pure ; if it be destroyed, the acid evidently, from that circumstance, contains nitric acid.

Nitric and *Hydrochloric Acids.*—These acids may generally be procured in a sufficiently pure state for all purposes of electro-metallurgy, or may be tested as follows :—Nitric acid should be quite free from colour ; and, by the way, should be kept in the dark after purchase : it should, for an equal bulk of water weighing 1,000 grains, itself weigh 1,500, the specific gravity of the acid being, to water, as 1·5 to 1·0. It may contain sulphuric acid, which may be detected by largely diluting the acid with water, and adding a dilute solution of either nitrate of baryta or chloride of barium. On a white precipitate appearing, the presence of sulphuric acid is evidenced. Another portion of the dilute nitric acid may have added to it a dilute solution of nitrate of silver, when a white precipitate indicates the presence of hydrochloric acid, derived from the impurities of the nitre, or nitrate of soda, employed in the manufacture of the nitric acid.

The hydrochloric acid should be colourless ; for, if yellow, it contains chloride of iron, and possibly other chlorides. It may be tested for sulphuric acid in the same manner as we have just suggested for nitric acid. The presence of iron is indicated by boiling the acid with a little nitric acid, and, when cool, adding a solution of the yellow prussiate of potash, when the iron will be precipitated of a blue colour. For special laboratory purposes in experimenting, pure nitric and hydrochloric acids may be procured of any

respectable chemist and druggist, or at the philosophical instrument-maker's.

In the same way, the following substances, previously named, may also be obtained in a state of purity, sufficiently so for all practical purposes—namely, *carbonate of ammonia; sal-ammoniac; fused caustic potash, or oil of tartar; carbonate of potash; sub-carbonate of soda; chloride of sodium, or common salt; caustic lime; calcined and carbonate of magnesia.*

Zinc, Oxide and Sulphate.—The sulphate is an abundant product when Smee's battery is employed; the waste solution affording it nearly pure on crystallisation; or it may be made direct by dissolving sheet zinc in dilute sulphuric acid, evaporating, and crystallising. Oxide of zinc is readily procured by adding either a solution of caustic potash, or soda, to one of sulphate of zinc, washing the precipitate, and drying it.

Iron, Oxides and Sulphate.—The sulphate is produced abundantly by the gradual oxidation of iron pyrites by air and moisture, either directly from that substance, or as an indirect product of it in the manufacture of alum. It is sold in the form of green crystals in commerce, that are more or less impure; but, by re-crystallisation, such may be procured in a much purer condition. It may be purchased, however, in an almost pure state, either at the chemist's or the drysalter's, at comparatively trifling cost. It is readily produced by dissolving a piece of good bar iron, or clean iron nails, in dilute sulphuric acid, such a solution being sufficiently pure for all practical purposes. The red or sesquioxide is easily procured by drying crystals of the sulphate, and then heating them in a furnace in an open crucible. The oxide, so prepared, is largely used for polishing, and is much sold for that purpose in commerce, under the names of *Crocus* and *Colcothar.* It is for polishing plated articles that it is chiefly employed in electro-metallurgy.

Copper, Oxide and Sulphate.—The latter is sold as *Blue Vitriol, Roman Vitriol,* and *Bluestone,* in commerce. The crystals should be large, regular, of a fine blue colour, entirely free from green. At times we have met with specimens containing a large quantity of sulphate of iron, which, being isomorphous with copper, will crystallise with it. This is a serious adulteration, inasmuch as both salts are rendered almost useless; and not only so, the cost of copperas, or sulphate of iron, is not a seventh of that of the sulphate of copper; so that, if the two salts could be used, the cost paid would have been far too great, and much pecuniary loss would be sustained. The black oxide is readily procured by heating the nitrate of copper to redness. It may be purchased, however, better at the instrument-maker's, who produces it for the use of the chemist in organic analysis.

Silver, Oxide, Chloride, and Nitrate.—The nitrate is now so abundantly produced for the use of the photographer, that it would be, except on a large scale, unnecessary for the electro-metallurgist to make it. Indeed, the present lowness of its price can only be accounted for, in a paying point of view, on the fact of its immense sale permitting of small profit. Lime, potass, or soda, in caustic state, precipitate the oxide, which should be abundantly washed with water. Similarly, the chloride is readily obtained by adding a solution of common salt to one of nitrate of silver. The method of doing this, and of testing the purity of nitrate of silver, have been already described at p. 267, *ante.*

The preparation of the remaining chemicals forming the remainder of the list given at p. 270 *ante*, will receive attention when separate directions are given for their preparation in practical electro-metallurgy.

We next turn to consider—

The Electrical Conditions.

The simplest view that we can take of electro-decomposition of compound substances, is, that the voltaic current disturbs, overrules, and re-arranges the chemical affinities previously at rest. Thus, a mass of common salt, or the same in solution, has no tendency to spontaneous decomposition; or, from the earliest period to the latest possible of its existence as matter, it would retain its composition absolutely unaltered, did no force act on it to effect decomposition. But if we present to either or both of its constituents—chlorine and sodium—any other compound, one element of which has a greater attraction for either of those constituting the salt; or if we submit it to the action of electricity, the quiescent affinity uniting the two elements is disturbed, and new forms of matter arise. For example, as illustrative of the first new condition, we present salt to nitrate of silver in solution; the chlorine having a greater affinity for the silver than for the sodium, quits the latter to unite with the silver, and a new insoluble substance—the chloride of silver—results; whilst the sodium, uniting with oxygen and the nitric acid of the nitrate of silver, forms a new compound, the nitrate of soda. But, as already stated, if the voltaic current be allowed to act on a solution of salt, the two elements become polarised; one appearing at the anode, and another at the cathode—distinct from each other, and evidently free.

The art of electro-metallurgy, therefore, so far as depending on the science of the question, consists in employing such an amount of electric force as shall be sufficient to disturb and re-arrange existing affinities, either by direct or secondary action. In all cases of *direct* action, the compound must be in solution, and composed only of two elements, as A+B, or AB; constituting thus what is termed a *binary* compound. Common salt, or chloride of sodium, Na Cl; iodode of potassium, KI; and water, HO,* are instances of three binary compounds.

In secondary electro-chemical decomposition, the result arises from different causes. The body may be composed of ABC—that is, three or more elements—or of two in greater than single proportion, as AB_3. Sulphuric acid is an instance

* For explanation of these symbols, see p. 268, *ante.*

of this kind; and although an excellent conductor as diluted with water, is not decomposed *directly* by the voltaic current. If mixed with water, the latter liquid undergoes decomposition. Liquid ammonia is another instance of the kind: it is composed of NH_3; that is, one equivalent of nitrogen united with three of hydrogen (dismissing the ammonium theory for the sake of simplicity at present). Now both of these may be decomposed by secondary action, but not directly by the voltaic current. The decomposition of sulphate of copper has been already shown to be effected by secondary action, in the quotation from Mr. Spencer, at p. 266, *ante*. Omitting its attendant water of crystallisation, its composition is indicated by the symbol Cu O, SO_3; that is, one equivalent of oxide of copper, and one equivalent of sulphuric acid. Now it is evident that three elements are present in it —namely, copper, oxygen, and sulphur. But even with secondary action of the nascent hydrogen, only a binary compound—the oxide of copper—is decomposed, the sulphuric acid being utterly unaffected, except in its separation from the oxide of copper, with which it was previously united to form the sulphate.

Although we shall have constantly to notice the fact hereafter, it may be here impressed on the mind of the reader, that readiness of decomposition by the voltaic current greatly differs in compounds. One of the most easily decomposed substances is the iodide of potassium, only a very feeble single cell being required for that purpose. Water, on the other hand, requires much greater intensity; and, consequently, except with a very intense single cell, more than one cell is ordinarily required to effect its decomposition. It is part of the duty of the electro-metallurgist to accommodate the intensity of the battery he employs to the requirements of the solution he has to manipulate with; for each increase in the number of cells employed, adds the same arithmetical proportion to the cost of the process. Thus, if two cells be used where one would answer, or three, and so on, so the cost is doubled, trebled, &c. On the other hand, doubling the *size* of the cell does not double the expense; because, by so doubling the size, the cell will do double as much work, all other circumstances being equal.

The terms *electrolysis*, *electrolyte*, *electrode*, *anode*, and *cathode* have all been explained previously. Faraday added others; thus *ions* from the Greek, signifying "to go," he applied to the elements of an electrolyte, or body capable of direct decomposition. Oxygen and hydrogen, for example, are ions in water. He particularised these ions, however, by calling such as go to the anode *anions*, and those going to the cathode *cations*. In water, oxygen is the *anion*, and hydrogen the *cation*; the latter appearing at the cathode or zincode, and the former at the anode or platinode. Anions correspond to what were, and are, called electro-negative bodies; whilst the cations correspond to the electro-positives.

In all works dealing with electro-chemistry, or electro-metallurgy, it has been customary to give a list of electro-negatives and positives; and we therefore feel compelled to follow the example first set by Berzelius. But it must be remembered that such a list only gives comparative, and not absolute, results; and any mistake made on this point will necessarily lead to serious errors. For instance, in the tables below, hydrogen is ranked as an electro-negative; whereas, when water is decomposed, it is a high electro-positive. So with all the substances named below; it must be remembered that each is *electro-positive* or *electro-negative*, comparatively, and not absolutely.

Electro-Negatives, or Anions.

Oxygen	Molybdenum
Sulphur	Tungsten
Nitrogen	Boron
Chlorine	Carbon
Iodine	Antimony
Bromine	Tellurium
Fluorine	Columbium
Phosphorus	Titanium
Selenium	Silicon
Arsenic	Osmium
Chromium	Hydrogen.

The following gives a list of—

Electro-Positives, or Cations.

Potassium	Nickel
Sodium	Cobalt
Lithium	Cerium
Barium	Lead
Strontium	Tin
Calcium	Bismuth
Magnesium	Uranium
Glucinum	Copper
Yttrium	Silver
Aluminium	Mercury
Zirconium	Palladium
Manganese	Platinum
Zinc	Rhodium
Cadmium	Iridium
Iron	Gold.

To give an instance of the fallacies that the above list may give rise to, let us take the position of carbon, iron, and platinum. They are each widely set apart, and yet they may all be used in nitric acid batteries—platinum in Grove's, carbon in Bunsen's, and iron in Callan's—with all but precisely the same effect. Many other instances of the same kind may be picked out to show how highly, comparatively and accidentally, nearly all of the elements acquire the electrical states in the order above given.

To Faraday is due the merit of having first pointed out the definite nature of electrolysis, and the laws that govern it. In Series vii., § 826, &c., he enunciates the laws as follows; and they deserve, or rather require, the deep study of all those engaged in electro-metallurgy:—

"1. A single ion—that is, one not in combination with another—will have no tendency to pass to either of the electrodes, and will be

perfectly indifferent to the passing current, unless it be a compound of more elementary ions, and itself subject to decomposition. Upon this fact is founded much of the proof adduced in favour of the new theory [Faraday's] of electro-chemical decomposition, put forward in a former series of these *Researches.*

"2. If one ion be combined in right proportions with another strongly opposed to it in its ordinary chemical relations—that is, if an anion be combined with a cation—then both will travel, the one to the anode, and the other to the cathode of the decomposing body.

"3. If, therefore, an ion pass towards one of the electrodes, another ion must be also passing simultaneously to the other electrode, though, from secondary action, it may not make its appearance.

"4. A body decomposable directly by the electric current—that is, an electrolyte—must consist of two ions, and must give them up during the process of decomposition.

"5. There is but one electrolyte composed of the same two elementary ions—at least, such appears to be the fact—dependent upon a law, *that only single electro*-chemical equivalents of elementary ions can go to the electrodes, and not multiples.

"6. A body not decomposable when alone, as boracic acid, is not directly decomposable by the electric current when in combination; it may act as an ion, going wholly to the anode or cathode; but it does not give up its elements, except, occasionally, by chemical action.

"7. The nature of the substance of which the electrode is formed, provided it be a conductor, causes no difference in the electro-chemical decomposition, either in kind or in degree; but it seriously influences, by secondary action, the state in which the ions finally appear. Advantage may be taken of this principle in combining and collecting such ions as, if evolved in their free state, would be unmanageable.

"8. A substance which, being used as the electrode, can combine altogether with the ion evolved against it, is also an ion, and combines in such cases in the quantity represented by its electro-chemical equivalent. All the experiments agree with this view; and it seems, at present, to result as a necessary consequence. Whether in the secondary action that takes place where the ion acts, not upon the matter of the electrode, but upon that which is round it in the liquid, the same consequence follows, will require more extended investigation to determine.

"9. Compound ions are not necessarily composed of electro-chemical equivalents of simple ions. For instance, sulphuric, phosphoric, and boracic acid are ions, *but not electrolytes;* that is, not composed of electro-chemical equivalents of simple ions.

"10. Electro-chemical equivalents are always consistent; that is, the same number which represents the equivalent of a substance, A [see *ante*, p. 269, for table of chemical equivalents], when separating from a third substance, B, will also represent A when separating from a third substance, C. Thus 8 is the electro-chemical equivalent of oxygen, whether separating from hydrogen, tin, or lead; and 104 is the electro-chemical equivalent of lead, whether separating from oxygen, chlorine, or iodine.

"11. Electro-chemical equivalents coincide, or are the same, with ordinary chemical equivalents."

Such are the laws which Faraday established as ruling all the decompositions effected by the voltaic current. He supported these assertions by means of a great variety and extent of experimental evidence; and they stood the test of time, and the investigations of many other philosophers, requiring only trifling modification to establish their universality.

Although the whole eleven enunciations are of the utmost importance, still, to the electro-metallurgist, those numbered from seven to eleven, inclusive, are especially so, because they deal with the principles on which the art can alone be successfully carried on.

Such we may therefore consider to be the basis on which electro-metallurgy depends. We next proceed to describe matters of a more practical character.

First, as regards conducting power, which is a matter of great importance; because, as already shown at p. 271, *ante*, electrolysis cannot take place unless the fluid operated on be a conductor of the voltaic current.

Practically, copper is the only metal that can be employed to convey the electric current from the battery to the decomposing cell or trough. It is the cheapest of the best conductors, very durable, susceptible of a high polish, or amalgamation, so as to form good connections, is readily soldered or brazed, and may be had in any desired form, and of a wire of almost any thickness. For operations on the small scale, No. 16 gauge wire is amply sufficient in thickness, provided the connections be short, and the battery power moderate. But, for large operations, narrow strips of the metal, cut from a sheet weighing four to six pounds, are desirable. Such strips, an inch wide, are amply large enough to conduct freely the electricity of the most powerful voltaic battery that has yet been constructed. In fixing such conductors permanently, as between the battery-room and the room containing the decomposing cells, care should be taken to insulate the conductors by covering them with vulcanised india-rubber, or some other such bad conductor; for if the wires or strips be affixed naked to a wall, a portion of the current will be lost by the conducting power of the moisture between the two conductors. Hence it is desirable to employ wire covered with gutta-percha in conveying the current to its destination. Any accidental contact between the two wires, or other chance of the current being diverted, is thus rendered impossible.

In making connections, simple twisting of the wire should not be trusted to: because, however close two wires may *seem* to be, it is impossible that they can be in actual contact. This may be hard to believe by the unpractised, but can be proved thus:—Polish brightly the ends of two copper wires, and twist them as tightly as possi-

ble together. Leave them in this condition for a week or two. On then untwisting them, it will be found that *all* the bright portion has become oxidated, diminishing in extent certainly as the wires are most closely approximated, but still showing that air and moisture have entered between the surfaces.

Some persons, to obviate this, amalgamate the ends of wires that are to be placed in contact by dipping them into a solution of nitrate of mercury. For a time this answers; but, shortly, the wire becomes so brittle that it will break with the least touch, and so piece by piece of a conducting wire will break away. If neglected, this may occur at any moment; therefore, unknown to the operator, the passage of the current may be at once stopped, and the entire operation put an end to. It is best, consequently, whenever practical, to solder the wires at *every* connection, and thus non-continuity of conduction will become impossible.

All wires that have long conveyed a voltaic current become brittle, their texture being converted from the fibrous into a crystalline nature. This inconvenience, however, is easily obviated. If such wire be heated to a low red heat, and kept in that condition for a short time, the molecular constitution of the mass becomes restored, and it is then as soft and supple as can be desired. For similar reasons we have, as a rule, periodically heated all platina plates or electrodes red-hot, as even they become brittle by use. In a fifty-cell Grove's battery we always thus heat the platinas before use, and thus not only is brittleness prevented, but they are kept in a clean condition.

It has been frequently stated beforehand, that the *quantity* of electricity that a cell of any kind will afford, depends on the size of the plates, their proximity, their conductivity, and the amount of chemical action going on. It hence follows, that the *larger the plates* of a cell, the *closer they are together*, the more *readily they conduct;* and the *more exciting* and *conducting* the fluids or fluid employed, the greater is the quantity produced. It is for this reason that any form of nitric acid battery affords so much power compared to Daniell's, Smee's, and earlier forms. On the other hand, we have equally shown that tension or power to overcome solid and liquid resistances, depends, for the same size of plate, on their number. To Professor Ohm, of Nuremberg, we are indebted for first reducing all these facts to their mathematical value. It is evident that, to obtain the whole of the electro-motive force that is generated in any form of battery, would be impossible. The practical engineer always makes allowance for friction, loss of heat, and other opponent causes, in estimating the power of a steam-engine. For example, in calculating the horse-power of one, the rule is, to multiply the area of the piston in square inches, by the pressure of steam per square inch, which will give the number of pounds active on its surface. The amount so obtained, multiplied by the number of feet the piston travels per minute, and divided by 33,000 (the unit of a horse's labour in that period), gives the horse-power of the engine *theoretically.* In practice, however, allowance must be made for loss of heat by the steam, its friction as passing through the ports or openings, back pressure on the piston of the used and escaping steam, friction of all the moving parts, &c., &c.

Now, in an analogous manner, allowances have to be made for the difference between the actual potency of a current produced by a cell, and its theoretical or absolute efficiency. If there were no friction in the steam and the moving parts of the engine, the calculated power would be obtained; but, in the presence of such interfering causes, from a fifth to a third of the original force is lost. Hence the absolute impossibility of attaining perpetual motion by any form of machinery, because of friction. In nature there are thousands of instances of perpetual motion; a most familiar one being found in the formation of cloud, dew, vapour, &c., by the evaporative power of heat; the recurrence of tides; and, external to the surface of the earth, the motion of the planetary bodies and their satellites. We have no reason to suppose that any of these have increased or diminished in the mass of matter they contain since they were first created. We have been unable to detect the most remote resistance afforded to their passage; for so regular is this, that to calculate an eclipse for ages previous, or subsequent to our era, may be done with an error infinitely too fractional to be expressed by figures, if comparison be made between the time of elapse and that of error.

Now, in respect to the voltaic current, Ohm and others have shown, that the actual force we can obtain from any combination, is equal to the real electro-motive force generated, divided by the sum of the resistances of all kinds, such as arising from imperfect conduction of solids and liquids used in the circuit, and every other cause opponent to the passage of the force. It hence follows, that, by increasing the resistances of all kinds up to the required extent, the actual force generated by a cell may be so neutralised, as to be imperceptible to the most delicate galvanometer.

It may, perhaps, be desirable here to suggest a very simple method by which the facts above stated may be impressed. For this purpose, a single cell of either Daniell's or Smee's battery may be used; but we shall suppose the latter, because greater simplicity and certainty of result may be obtained by its use. Attach the two conducting wires of the battery to a simple form of a galvanometer with a single wire, and charge the battery with a dilute solution of acid, so weak, that, when fully charged, the needle shall not be deflected more than 30° or 40°.

Next remove one of the wires from the galvanometer, and dip its extremity into a trough two or three feet long, a few inches wide and deep, the trough being filled with a strong solution of sulphate of copper. Attach a fresh wire to the galvanometer, in place of that previously coming from the battery, and which is now supposed to rest in the copper solution. Bring the

other end of the fresh wire into contact with the wire in the trough: if the connections are all correct, the needle of the galvanometer should now, of course, be deflected to an amount equal to what it was when the battery wire was attached. Next remove the end of the fresh wire in the trough, little by little, from the battery wire, so as to have a gradually increasing distance in the solution into which they both dip. As this is done, it will be found that the deflection of the galvanometer needle gradually decreases; and if a trough sufficiently long be employed, the *resistance afforded by the length of solution between the wire of the battery and that of the galvanometer, may be made exactly to equal the electro-motive force of the battery;* and, consequently, the needle will return to zero, or 0°, showing the complete practical annihilation of the current by the resistance offered to its tension.

If, instead of a solution of sulphate of copper, one of common salt be substituted, then one of river, and lastly one of distilled water, carefully washing the trough out at each successive trial, it will be found that each of the above liquids will, for successive *shorter* lengths, afford an equal resistance to the longer one of sulphate of copper.

From the preceding simple experiment, there may be, therefore, learned the effect of fluid resistances in diminishing the amount of electro-motive force of any cell. Mathematically, the subject may be stated thus. Let—

x = The actual force.

E = The total electro-motive force produced by the battery.

R = The sum of all resistances.

Then—

$$x = \frac{E}{R}$$

Ohm offered other mathematical formulæ, that will at once suggest themselves as desirable from a consideration of the law about to be explained; but that will not assist any ignorant of algebraical formulæ, of which class many of our readers will be comprised. We shall quote, from Professor Wheatstone, the following enunciation of general laws regulating the amount of working force any battery will afford. He states them as follows:—

"1. The electro-motive force of a voltaic circuit varies with the number of the elements, and the nature of the metals and liquids which constitute each element, but is in no degree dependent on the dimensions of their parts.

"2. The resistance of each element is directly proportional to the distances of the plates from each other in the liquid, and to the specific resistance of the liquid [see the experiments just previously suggested on different liquids]; and is also inversely proportional to the surface of the plates in contact with the liquids.

"3. The resistance of the connecting wire of the circuit is directly proportional to its length, and to its specific resistance [that is, the varying conducting power of different metals], and inversely proportional to its section."

The last law is not one of great practical importance to the electro-metallurgist, because he can at all times regulate the thickness and length of the wires he uses for his purpose, the conducting power of a copper wire being many million times that of the solutions he employs. In electro-telegraphy, however, the resistance of conducting wires is a matter of the utmost importance; and, in fact, is a chief element of consideration; for just as on a railway, if there be frequent inclines, the power of the engine is constantly taxed to fresh efforts, so, in a telegraph wire, the resistance increasing with the length calls for a constant use of a large number of plates to produce sufficient electro-motive force to overcome it.

The preceding remarks and suggested experiments will suffice to show some of the most important electric conditions in regard to the working of the battery and decomposing cell, so far as electro-motive force is generated, conveyed, or conducted, and resisted in its action or passage. From the narrowness of our limits, we have been compelled to call attention only to leading features of the subject; but we believe that a careful study of what has been advanced, together with a repetition of the experiments that have been mentioned, will suffice to put into the possession of an intelligent person sufficient knowledge of the scientific bases of electro-metallurgy. We need only add, that the different questions we have briefly discussed, have occupied the attention of some of the greatest philosophers that modern civilisation can boast of in all countries where science is studied. To have therefore given only an epitome of what has been discovered, proved, and established would have been impossible. But a large proportion of such information would be quite valueless to the practical man, who desires to know the reason of what he is doing, rather than to enter into a personal investigation of the truth of all that has been advanced. This any one may get by practice; for, as the art is followed, all the laws, facts, &c., that have been stated, will gradually be more or less verified.

Hitherto we have supposed that the voltaic battery alone is the source of the electrical current employed in electro-metallurgy; but such is not the case; for electricity, as afforded by magnetic induction, is now largely and economically used. Practically, indeed, *motion*, generally that of the steam, is the prime cause, in place of chemical action, but combined with magnetic induction.

*The Magneto-Electric Machine.**—To describe this machine properly, will require that we should enter into a brief account of the nature of induction, as effected both by the voltaic current and the magnet on insulated wires.

If a few yards of copper wire, covered with either silk or cotton, be made into a helix or coil by bending it round a core—as, for instance, a gutta-percha tube—a few inches long, and an inch in the bore, the two extremities

* See, also, separate article on this subject, in a later portion of this work.

of the wire being left free, and the coiled portion on the tube be evenly laid like the cotton on the ordinary cotton reel, and a piece of soft iron rod be introduced into the hollow of the gutta-percha tube, so that the ends of the iron shall protrude an inch or two at each extremity, as represented in the following cut, of course, by

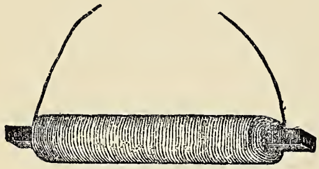


Fig. 172.

the simple placing of the iron rod in such a coil, no effect will be produced. If, however, the two ends of the coil be connected with a cell of any modern form of voltaic battery in good action, then immediately that the voltaic current passes, the iron will acquire magnetic properties, as may at once be evidenced on holding a few iron nails at either extremity of the iron rod, when they will be powerfully attracted, and remain adhering to the iron so long as the current of electricity passes over its surface. But, on disconnecting the wires of the coil from the battery, if the iron be pure and soft, the nails will immediately fall from the iron, because almost at the instant the current ceases to pass, the magnetic effect also ceases. If, in place of soft iron, a rod of steel be substituted, then, instead of the metal losing its magnetism on the current ceasing to pass, it will be found that the steel has acquired permanent attractive and polar powers; in fact, that it has become converted into a magnet.

This result arises from what is called electro-magnetic induction; for when a current of voltaic electricity passes in a direction at right angles to a magnetised bar, they mutually affect each other.

But just as we can induce magnetism by electricity, so can we also induce an electrical current by magnetism; and hence we infer still further the intimate relation that subsists between these two forces.

If the bar of iron be removed from the coil shown in the above cut, and the ends of the coil be connected with the galvanometer already described at page 253, and the poles of a powerful magnet be quickly introduced into and withdrawn from the coil, a current of electricity will be generated, which will be evidenced by the deflection of the needles of the galvanometer. It is on this principle that the all dynamo-electric machines, now used for electric lighting, electro-plating, etc., are now constructed. Into the details of these machines we cannot here enter.

It may be here observed, that the quantity that may be developed in these machines chiefly depends on the sectional area of the wire employed; whilst the intensity depends chiefly on the length of the wire, independent of its sectional area; and thus, so far as surface and length or number of coil revolutions are concerned, an analogy subsists with the question of size and number of plates as used in the voltaic battery for the production of quantitative and intensive effects.

It will be evident that this method of obtaining an electric current has many advantages that the voltaic battery does not possess. It cannot readily get out of order, if constructed properly at first. It requires little or no attention, and that chiefly to keep it clean, especially at the surfaces, where contact is made and broken. There is no "mess" with acid, or other exciting solutions; no amalgamation, use, and waste of zinc; and, in fact, its only cost is the coal required to drive the steam-engine that sets it in motion. There is no wonder, therefore, it is now generally preferred to the voltaic method of obtaining the electric force.

For electro-plating small objects, no form of voltaic battery equals that of the platinised silver and zinc arrangement of Mr. Smee. It has the advantage of requiring but one exciting fluid—dilute sulphuric acid. The only objection to it is, that, when in strong action, it sends off a kind of vesicles of acid vapour attached to the escaping hydrogen; but this is easily got rid of by ventilating the battery-room, or by placing a small battery under a hood; in the latter case the annoyance, however, is but trifling, and causes no unpleasantness.

Before concluding this account of the chief electrical and other conditions, etc., of electro-metallurgy, we may quote, as given in Mr. Noad's able *Manual of Electricity*, the following table, showing the relative powers of various modern forms of voltaic batteries; adding, subsequently, a few remarks of general application in the art.

Frequently, in the preceding pages, we have pointed out the distinction between quantity and intensity; but especially at p. 276, *ante*, to which we refer those of our readers who desire to refresh their memories. Suffice it to say, that, by means of the magnetometer, an instrument that we need not here describe, the following results were arrived at:—

"Three voltaic elements [single cells] were constructed, as nearly as possible alike in size and surface. 1st. A Grove's nitric acid battery, immersed in a suitable flat diaphragm, external to which were a pair of corresponding zinc plates. 2nd. A Daniell's sulphate of copper battery, having a copper plate four inches square, and a diaphragm and zinc plates similar to the first. 3rd. A Smee's battery, of similar dimensions, but having its zinc plates equi-distant [from each other] with those of the other batteries, in order to place each arrangement under the same conditions, with the exception of the unnecessary diaphragm. 4th. A Smee's battery, with the zinc plates at the ordinary distance from the silver one.

"These batteries were first tested as to the relative quantities of electricity excited by each, by employing a short helix of large dimensions, consequently opposing little or no resistance [see *ante*, p. 276], the wires being united so as to

form a helix twelve feet long, and twenty-four wires in thickness. Secondly, they were tested for intensity by uniting the wires end to end, so as to form a single wire 288 feet in length, this opposing great resistance. The results are given in the following table :—

" *Table showing the Comparative Power of Grove's, Daniell's, and Smee's Batteries, in relation to Quantity and Intensity.*

INTENSITY.

Grove's	87
Daniell's	43½
Smee's No. 1 open plates	27½
Smee's approximated plates	32

QUANTITY.

Grove's	44
Daniell's	12
Smee's No. 1 open plates	42
Smee's approximated plates	49."

Mr. Noad adds—" Thus it appears that nearly equal quantities of electricity are excited by equal surfaces of Grove's and Smee's batteries ; but that electro-motive [see *ante*, p. 277] force, or intensity of the nitric acid battery, is rather more than three times that of Smee's. Daniell's arrangement holds an intermediate position with regard to intensity, but is deficient in quantity."

The preceding tables, however, cannot be relied on absolutely, for several reasons. In the first place, the strength of the acid solution next the zinc is not stated ; and an equally important consideration is also that of the strength of the nitric acid of Grove's, and the sulphate of copper solution employed in Daniell's ; equally so, in respect to the latter, is the question of temperature. In regard to Grove's and Smee's arrangement, the latter point is scarcely deserving of consideration. We have had fifty cells of Grove's and of the carbon nitric acid battery at work in the open air throughout the winter, often during the last twenty years ; and they work apparently as well as in a warm room. But if Daniell's cells be employed, and worked during cold weather—say below an external temperature of 40°—the quantity and intensity are both greatly reduced to what is obtained at a temperature of 60°. The following simple but instructive experiment will aptly illustrate the question. Charge any form of Daniell's battery—but preferably one in which the copper solution is held in an external copper cylinder, as the form in which Daniell first brought it out—with the copper solution and the dilute sulphuric acid, both at a temperature of 40°. Connect the wires with the simple galvanometer of a single wire. Notice the deflection when the needle is steady. Next place the cell in a trough of warm water, and add more of the latter, so as to gradually raise the temperature to 65° Fah. As the temperature rises, the deflection of the galvanometer increases, and may be greatly enlarged until the boiling-point of water is arrived at. Thus, from this and many other considerations that we might urge, the preceding tables, although of decided value, must not be relied upon beyond giving approximate results in reference to correctness.

There are numerous other matters, perhaps more of practical detail, that must eventually come under notice ; but directly connected with what has been previously remarked on, is the position of the electrodes in a decomposing cell, as affecting the amount, character, and quality of the metal deposited in the trough wherein electro-metallurgical operations are carried on. In respect to this, we cannot do better than quote the observations of an eminently practical man, Mr. Gore, whom we have formerly referred to. He remarks—" The position of the electrodes has a considerable influence upon the phenomena of electro-deposition. For instance—1st. If the two electrodes in a depositing liquid are horizontal, with the anode above and the cathode below, the salt formed at the anode will, by virtue of its greater specific gravity, sink in the liquid; whilst the acid set free at the cathode will, by its less specific gravity, rise upwards ; and thus the anode will be constantly supplied with fresh uncombined acid, the cathode will receive a constant supply of metallic salt, and deposition will continue without interruption. 2nd. If the two electrodes are vertical in the liquid, and opposite to each other, similar differences of specific gravity will cause the lower part of the liquid to become saturated with metallic salt, and its upper part to consist of free acid mixed with the water : in consequence of this, the current of electricity will almost wholly pass from the upper part of the anode diagonally downwards through the liquid, to the lower part of the cathode ; and thus the upper part of the anode will dissolve rapidly, whilst its lower part will dissolve but slowly ; and the cathode will receive a rapid deposit at its lower part, and but very little at its upper part. In this position, vertical lines, and even deep grooves, are sometimes produced in the deposit (especially if the position of the cathode be slightly overhanging), by the ascent of streams of the lighter acid liquid from which the metal has been exhausted by deposition. If the solution be nearly a saturated one, and has been freely worked without stirring or disturbance for some time, crystals of the metallic salt are apt to form all over the lower part of the anode, which will be dissolved very rapidly at the surface of the liquid, and appear as if cut by a knife. In addition to these effects, if the solution be a very deep one, with much free acid, two independent currents of electricity will be developed, one in each electrode, by the unequal action of the two different strata of liquid upon their upper and lower parts."

This is a matter that has already, in part, been dealt with at p. 271, *ante*. It may be still further illustrated by the following cut. A represents a tall glass vessel, in which is placed a strip of copper, B, one end of which rests on the bottom of the vessel. C represents a liquid of lighter specific gravity than D ; the latter may be a saturated solution of sulphate of

copper, and C a dilute solution of sulphuric acid in water. The heavy sulphate solution is first poured into the vessel; and the lighter dilute acid is then passed through a funnel with a long neck, the bottom of which should just rest on the top of the sulphate solution. By this the former may be made to swim on the latter. On introducing the strip of copper, a current will be generated between C and D—the copper being positive in C, and negative in D. Hence will appear the necessity of keeping the solution in a decomposing trough of equal specific gravity in every part. This is usually effected by occasional stirring.

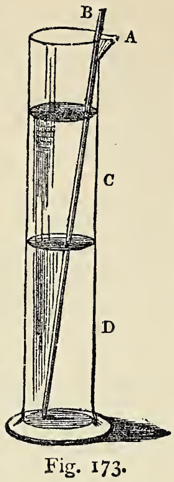


Fig. 173.

In respect to the influence of temperature on the rapidity of deposition, sufficient has already been stated at p. 271. So great is it in some instances, that when an "electro" of a wooden or other cut is required as quickly as possible—as in the illustrated papers—the copper solution is kept at a very high temperature; and the "electro" is consequently obtained in about one-fourth of the time usually required at ordinary temperatures. The reason of this has been already explained. The following singular circumstances, in regard to temperature, are remarked on by Mr. Gore.

"We have repeatedly observed that, with some solutions used at a high temperature for depositing, the cathode being immersed in the liquid at the ordinary atmospheric temperature, and the liquid then heated to the desired point, no conduction or deposition took place; nor did it occur when the receiving metal was taken out, washed in cold water, and re-immersed. But if the temperature of the liquid were first raised, and then the cold cathode suddenly immersed, deposition took place freely, and the liquid might be cooled down many degrees without stopping the action. In coating iron and tin in some solutions, the iron being immersed before heating the liquid, no deposition took place, even at 150° Fah.; but if the liquid were first heated, deposition occurred below 100° Fah."

Another point to which attention may be drawn, relates to the mechanical conditions of the surfaces of both anode and cathode. It has already been stated, at a preceding page, that the same piece of metal roughened on one surface, and polished on the other, will afford an electric current if immersed in an acid solution. This shows the high importance of mechanical conditions; and is still further illustrated as follows:—If the platinised silver of a Smee's battery be removed, and one of polished silver be substituted for it, and of exactly the same size, the effective amount of electricity produced by the latter arrangement will be found to be greatly inferior to that of the platinised silver; for the minute points on the latter facilitate the contact of the metal with the surrounding liquid, and, consequently, increase the number of active surfaces. Again, if two pieces of platina be taken as electrodes, and plunged into acid and water, being connected with a couple of cells from any modern form of battery, one edge of each electrode being cut perfectly level, whilst the other is made jagged like the edge of a saw, it will be perceived that the gases of the decomposing water will first rise at the rough edges, and a few seconds will elapse before the bubbles make their appearance on the surface of the polished surfaces.

We learn from this, that an irregular or rough surface on a cathode will tend to make a rough and unequal deposit, because the action is unequal. Hence, in depositing thick masses of copper, the back frequently presents nodules or knotty masses that had their first origin in some slight projection; but, having been once formed, rapidly progress to increase. A rough cathode has a tendency to make a deposit crystalline in its character.

Lastly, in the enumeration of the general conditions, of a scientific nature, that have to be examined and described, is one touching the economy of battery power. On this subject we have already dealt slightly when investigating the chemical conditions; but here it must be more fully inquired into.

If a single-cell apparatus be employed, as represented and described at p.265, Fig. 171, *ante* (in which the zinc is enclosed in a porous cell with dilute acid, whilst the mould is immersed facing it in a metallic solution—say sulphate of copper—and connected with the zinc by a wire), an equivalent of copper is deposited for each equivalent of zinc dissolved. By this we mean, that whilst 32·6 grains of zinc are being dissolved in the porous pot (provided the zinc is well amalgamated), then 31·7 grains of copper are deposited on the mould.

Again, if, instead of the mould being placed as above (forming part of the battery), it is transferred to a separate trough holding a solution of sulphate of copper, and attached as the cathode of a single cell, whilst opposite to it is an anode of copper, 31·7 grains of copper will be dissolved from the anode, and precisely the same amount will be deposited on the cathode; and in the battery cell, 32·6 grains of zinc will be dissolved for each 31·7 grains of copper deposited in the decomposing trough.

But if *two* battery cells be employed to deposit on *one* cathode in the decomposing trough, then 65·2 grains, or 2 × 32·6 grains of zinc, will be dissolved in the two batteries, collectively, for 31·7 grains of copper deposited; and just as the *number of batteries* is increased, so, in exact proportion, is the increased expenditure of zinc for the same amount of work effected.

On the other hand, supposing one battery cell has sufficient electrical power to work two, three, four, or more decomposing troughs, then the expenditure of zinc, for the same amount of work done, is reduced to half, one-third, one-

fourth, and so on, respectively, according to the number of troughs worked by one cell. Theoretically, any number of troughs might be worked by one battery; but, practically, it is impossible; because, as the number of troughs is increased, the resistances afforded by the wires (which is trifling) and of the liquids (which is enormous), impose limits that cannot be passed; and the reason of which has already been pointed out when we discussed Ohm's formula, and the doctrine of resistance generally, at p. 277, *ante*.

The element or condition of time, *generally*, has been one of constant remark throughout the preceding pages, directly or indirectly; but, *specifically*, the following facts have to be stated. "The character of the deposited metal is very much influenced by the rapidity of deposition. If it be deposited *very rapidly*, it will be in the state of a perfectly black, soft, non-coherent powder, or sponge. If deposited *more slowly*, it will possess the ordinary character of the particular metal. And if deposited *very slowly*, it will be crystalline, because the atoms are then allowed sufficient time to arrange themselves in the crystalline form."

We have thus investigated all the leading conditions that affect the deposition of *all* metals; and next have to reduce such conditions to practice; show their modification under certain circumstances; and, generally, to enter on the practical details of the subject.

It is evident, from what has been stated, that many branches of science are involved in the practice of the art; for the laws of heat, gravity, electricity, magnetism, and chemistry are all connected with it, and the phenomena generally of these sciences equally so. Perhaps no branch of art and manufactures is connected with so many departments of experimental philosophy. We have omitted one science, that of optics; because, except under very special circumstances, that rarely arises in practice. *Light* has no known influence in electro-metallurgical processes. But viewing the connection between electro-metallurgy and philosophy, a very interesting series of results has arisen. Speaking roughly from memory, we believe that about thirty-five years have elapsed since we heard a lecture by Mr. Grove, in the theatre of the London Institution, Finsbury Circus, on the art of engraving and printing by light and electricity. On that occasion Mr. Grove handed us an engraving of the front of the Institution, that had been made, first by taking a daguerreotype on silver plate, and then etching this by electro-chemical action. This was, we believe, the first successful attempt (at least in this country) in which a number of engravings had been thrown off from the press, the original plate having been engraved by the two forces of nature. The next great advance in the art was the discovery, by M. Pretsch, of Vienna, of a process by which engraved plates of great practical value could be produced. Taking advantage of the fact that a mixture of gelatine and bichromate of potash hardens when exposed to light, he applied it to produce photographs. The glue, bichromate, nitrate of silver, and iodide of potassium having been all melted together, were poured on to a flat glass plate, and allowed to dry in the dark; a photograph, or an engraving on paper, was then placed face downwards on this; and the whole was exposed to daylight for some time. Wherever the light penetrated, there the glue became hardened; whilst the dark or shaded portions of the photograph or engraving, prevented the action of light on the glue. The plate, after due exposure, was soaked in water; and those parts that had been unacted on by light, immediately rose above the previous level; whilst the parts that had been acted on, maintained their previous level. Consequently, a glue plate was thus produced which had been completely engraved by light alone. A mould was made of this, and exposed to electro-metallurgical action; the result being a copper plate—an exact facsimile of the original; and from which a number of engravings on paper (400 and upwards) could be obtained in the usual way.

Step after step has been made since this invention; and now the electrotype and photography have become arts progressing together in producing results that, in the early days of Faraday, could not have been imagined as possible. As discoveries in science have progressed, so these arts have gone on to perfection, and, at the present time, exert a most powerful influence on popular taste, as the latter, by reaction, equally stimulates the progress of the arts.

A century has not elapsed since Galvani and Volta conducted the first experiments in connection with the current electric force; and not half a century since Œrsted showed that an electric current had the power of deflecting the magnetic needle. But, within the last thirty years, what results have sprung from such (then) apparently trifling causes! The art of electrotyping—a revolution in all manufactures of precious metals, beneficial alike to the health and material prosperity of thousands, and tending to popular refinement by the ready multiplication of works of art at little cost; our telegraphic systems on land and beneath water; with many other minor inventions, have arisen; and, perhaps, more than any other science, has electricity thus, within an ordinary lifetime, worked its wonders for the good of mankind.

ELECTRO-METALLURGY IN PRACTICE.

The great variety of objects to which the art of electrotyping is now employed, practically splits up the subject into a great variety of details, and makes it one of a considerable extent in regard to the description of the various processes involved in manipulation. Consequently, numerous hand-books and other works have been published, each professing to give accurate advice of a practical nature in all respects. Many of them are excellent in their way; but, at the outset of the practical part of the present one,

we cannot help remarking, that all attempts to present in books the minute details of any art or manufacturing process, must necessarily fail, simply because no individual can possibly be acquainted with all the varied conditions that may be presented; hence we urge this point as an apology for any shortcomings that the present work may be blamed for.

Again, in almost every department of manufacturing industry, what are called "secrets of the trade" exist. These, simply translated, mean new methods, by the exercise of which the inventor, or his workfolk, succeed better than others in producing certain results. Occasionally, such novelties may be of the highest practical value; and equally, at times, they may prove highly delusive. Much depends on the managing head of any concern being capable of distinguishing between these two extremes; and in the history of electrotyping, taken as a whole, it will be found that no branch of applied science has been so favoured by the application of high intelligence and knowledge of scientific principles to practical purpose. In almost every case patentees for improvements in electrotyping processes have been persons previously favourably known in scientific circles, and, at the same time, possessed of sufficient business habits to turn their knowledge to good account.

The objects to which practical electro-metallurgy is applied are exceedingly numerous, and might be almost indefinitely increased. In the early branch of the art a vast number of projects for its application were brought forward; and in more than one instance the projector was ruined. Novelty catches both the scientific and popular worlds, and far too frequently proves that a little knowledge is, indeed, a dangerous thing.

The objects of electro-metallurgy must depend on the metals that can be conveniently deposited. The great proportion are practically of little value; indeed, at the present day, we may confine the ordinary practice of the art to very narrow limits; to the deposition of copper, silver, gold, nickel, and iron, the latter being almost exclusively employed as a protecting coating to engraved copper plates, as first proposed and patented by M. Joubert. Each metal requires some modification in the process of its deposition. Thus copper is best deposited from its solution as a sulphate; gold and silver are preferably deposited from a solution of their cyanides; whilst iron is most conveniently dealt with in connection with its chloride or sulphate, nickel with the cyanide or sulphate, &c.

It must also be borne in mind, that whatever the object of the deposition of a metal may be, the mechanical condition of that deposit greatly influences its commercial value. For example, at a previous page, we partly described the method of M. Pretsch (see *ante*, p. 281), by which light and electricity were made obedient servants to the art of engraving. But exact and beautiful as were the results obtained by that invention, they were all but practically useless, because copper deposited by electro-metallurgical action, is far too soft to produce a plate that will stand the wear and tear of the copper-plate printer's operations; hence the electrotypes produced by that ingenious process gradually got destroyed, so far as the engraved surface was concerned, after a few hundred impressions had been taken from the plate. As a rule, all metals deposited by electricity are softer than those produced by rolling and hammering. These mechanical operations tend to cause the particles of the metal to get into close contact; and hence they acquire a hardness that enables them to resist friction and other destructive action that electro-depositions are incapable of resisting. On the other hand, whilst, for example, a piece of Sheffield plate was rendered quite useless when the silver was worn off, an electrotyped surface may be renewed *ad infinitum;* so that, practically, in a majority of cases, the defects of electro-metallurgical processes are counterbalanced or remedied by the peculiarities that distinguish them from all others, but especially by the facility of their execution.

In commencing electro-metallurgy as a matter of business, therefore, it is essential to bear in mind the branch of it that is intended to be pursued. The deposition of copper, silver, and gold proceeds on precisely the same *principles* in each case; but the practice greatly varies. Therefore, in fitting up an establishment, its arrangements must essentially depend on the objects that are to be carried out.

It rarely happens that all circumstances desirable for any purpose can be commanded; but some may be essential, whilst others are of but minor importance; and the consideration of both should, therefore, be carefully entered into. Take, for example, first, the question of purity of water. At p. 271, *ante*, we have pointed out how essential this is in respect especially to manipulating with the precious metals; but in every case, as there shown, the greatest possible care should be taken to obtain a supply as free as can be from organic, and equally inorganic, salts, &c. Some years ago we had to carry out a particular object in chemical manufactures, for which soft water was absolutely essential. For the purpose of discovering a suitable supply, we traversed a large portion of England—analysing, at various places, the water-supply, natural or artificial. We found only two sources, between the north of Yorkshire and the south of Kent, that could be used for water-supply; and hence can quite sympathise with the difficulty the practical reader may have in such a selection.

The author from whom we have previously quoted, well observes—"The first step in practice is to consider the probable magnitude of the operations to be carried on, and to provide rooms of a suitable size. These should be upon the ground floor (except for electro-gilding), well lighted and ventilated; with conveniences for the erection of boilers and drying flues, for placing washing-troughs, depositing vats and batteries, and for the escape of unwholesome vapours: there should also be ready access to a plentiful supply of clean water. The establish-

ment should consist of at least three rooms, and an open yard with an out-house; an upper and more private room for gilding; a ground room for silvering; and another ground-floor room for the coarse work, such as coppering, brassing, and the preparation of the larger and coarser articles for receiving deposits. The out-house is for the batteries, and the yard for washing the battery cells. If a magneto-electric machine be employed, an additional small, dry, and clean apartment will be required, which should be reserved for it alone."

Of course, sources of heat must be provided for a variety of purposes; and the same authority deals with these questions as follows:—

"For the purpose of general deposition, several large iron boilers, with furnaces beneath, either in the coppering-room, or in close proximity to the silvering-room, are required. These are to contain solutions of caustic potash for cleaning articles. A low furnace should be erected between those rooms, having a long horizontal flue covered with plates of iron, for drying deposited or plated articles upon; the room for coppering should be furnished either with a low furnace or stove for heating the solutions used for coppering or brassing iron. Each room, whether for coppering, silvering, or gilding, should be provided with a tap of running water, and a leaden trough beneath, for washing the smaller articles; and the coppering-room should be furnished with one or two large wooden tubs or troughs, filled with water, for washing articles of larger size. This room and the out-house should contain a number of large stoneware pans and jars, oval and round, of different sizes and proportions, to receive the various 'pickling' and 'dipping' liquids, acids, or 'spent solutions.' Several large iron trays, filled with sawdust, should also be provided and fitted to the furnace flue, for drying plated and deposited articles upon. Each of the rooms should be provided with a 'scratch-brush lathe,' for scouring the various articles. The gilding-room should have several small stoves, for heating gilding solutions; or, in lieu thereof, several iron tripods, with large gas-burners beneath. The silvering and coppering-rooms should each be provided with one or two pairs of large and well-insulated copper wires, proceeding from the depositing vats to the batteries outside. The gilding-room will not require these, small batteries only being used in it, which are kept in the same room."

Various forms of the scratch-brush lathe, above mentioned, have been recommended. In the following cut one of them is represented. It consists of an ordinary lathe, A, with a wooden chuck, B, to the sides of which are firmly secured four horizontal bundles of fine brass wire; above it is a vessel, C, containing stale beer, which is allowed to drop constantly by the pipe, D, upon the revolving brushes whilst they are working. The sides, E E, are intended to prevent splashing; and the tray, F, and pipe, G, serve to collect and remove the waste liquid. The workman stands opposite the end of the machine when using it, working the treadle with his foot, and pressing the article to be cleaned against the end of the revolving wire brushes, exposing, in succession, different parts of the article to their action. Wire of varying degrees of fineness is used with different articles.

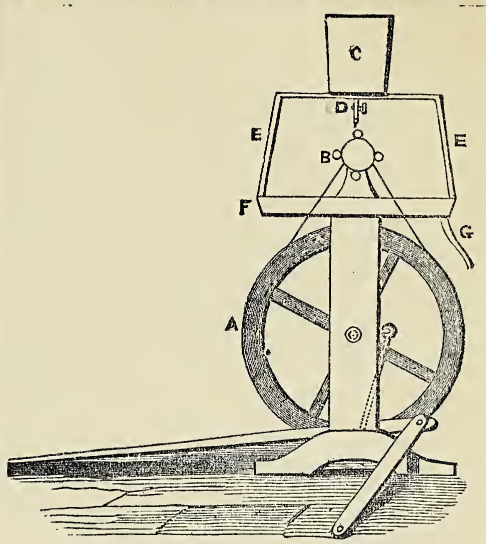


Fig. 174.—Scratch-brush Lathe.

By means of this instrument, the rough dirt, oxide, &c., on articles to be plated, are thus removed to a considerable extent.

On the source of the electrical current we have already expatiated sufficiently in our previous pages, where every modern form of battery has been described. The most effective kinds of the magneto-electric machine will be afterwards described. Sufficient instructions have been given on all points in respect to the arrangement and management of apparatus, to an extent that leaves us nothing to add, except to request the practical reader to take to heart the advice and instruction that have been proffered him.

In choosing the zinc for batteries, the best rolled sheet is always the cheapest. Cast zinc, as imported in plates as *spelter*, is full of impurities, that tend to its rapid destruction, even if well amalgamated; whilst sheet zinc, especially that technically known as Mosselmann's, imported from the continent, is by far the cheapest in use. The thickness of the sheets varies, but one of a quarter to three-eighths of an inch answers well. We have already urged the prudence of thorough amalgamation. On the large scale, this may be effected as follows:—Immerse the zinc plates in a pickle, composed of one part of strong sulphuric acid, free from nitric acid or its compounds (see *ante*, p. 272), with twelve parts of water, by measure, letting the solution get cold before use. Turn the plates over, so that both sides may be well exposed to the acid's action, and rub them, at the same time, over their surface with a woollen cloth attached to the end of a stick: by such means the plates will be cleared of all adherent oxide, &c. Prepare a similar acid solution in an earthen

vessel, and into this also pour in a quantity of mercury. Take zinc by zinc from the first acid, and introducing each successively into the fresh one, rub in the mercury by means of a stiff brush, or woollen cloth, until the surface of the metal gathers a brilliant polish, and will not easily take up more mercury. Remove the zincs into an oblong trough, which should be higher than the zincs, and immerse them in it, filling it with water, and allowing a stream of the latter to pass through the vessel; but do not let the zincs touch each other. After a time the excess of mercury that the zincs have taken up will run off; and after their removal from the trough it may be collected, and returned to the amalgamating vessel, to be used afresh. A great loss of mercury frequently occurs through neglect of a systematic method like the one we have recommended, and also from throwing away spent battery solutions. The contents of any vessel in which amalgamated zinc has been employed for a battery, should be poured into a porcelain vessel. The water or salt solution will run over; but any drops of mercury that have dripped from the zinc will fall to the bottom of the vessel, and may be collected. In the course of a year we have known pounds of this metal thus saved in an active laboratory, that would otherwise have not only been cast down the sink, but would have eaten away the lead pipe, soldering, &c.; and hence, besides the loss of metal, caused great expense in effecting the necessary repairs of the pipes.

Occasionally, a considerable quantity of waste amalgamated zinc will accumulate. This may be economised most effectively by adding to it more mercury, so as to make a semi-fluid amalgam. If this be then transferred to a porous pot placed in a porcelain pot containing dilute sulphuric acid, and a piece of platinised silver be made to form a coil or circular sheet around the porous pot, with the usual wire connections, a circular Smee's battery may be made of considerable power. Gradually, in such an arrangement the zinc will dissolve away, making, by its amalgam, whilst it lasts, the positive element of the battery, and leave the mercury in its fluid state, when the latter can be restored to the amalgamating trough for the purpose of coating new or old zinc plates. We know of no better way than this of economising both zinc and mercury, as distillation, or re-melting old amalgamated zinc, are both troublesome and expensive, occasioning, in the one case, loss of zinc, and in the second, loss of mercury.

Depositing troughs have been made of all kinds of materials, shapes, &c. Of course, no material equals glass in value; but it is at first expensive; and, not only so, cannot be made of very large size without danger of fracture. Next to glass is the best kind of earthenware; but this is liable, especially with solution of sulphate of copper, to disintegrate and fall to pieces; and even the best ordinary white porcelain, expressly made for the purpose, will not last long. For copper deposition, a wooden trough, of an oblong figure, as represented in the following cut, answers perfectly well. The joints should all be dovetailed, and smeared over with white lead before being put together, and the inside well lined with pitch, or a mixture of pitch, tallow, rosin, and chopped hemp—the

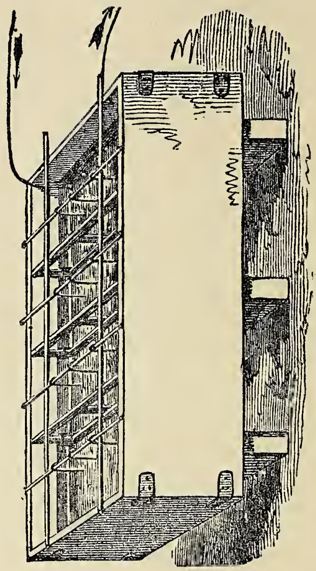


Fig. 175.—Depositing Trough.

tallow giving softness, and, with the hemp, tending to prevent any danger of the coating cracking. But if such a trough were used with cyanide solutions, the pitch would be speedily dissolved off, and the solution be completely spoiled; consequently, when possible, glass or porcelain should be used for plating and gilding solutions. Enamelled cast-iron has been recommended, and used; also troughs lined with gutta-percha; but which, like pitch, must not be employed when cyanide solutions are in use. In the preceding cut, two external wires represent those coming from the battery, or the magneto-electric machine, conveying the current to the articles suspended in the decomposing trough. This is crossed by metal bars, from which the objects to be plated, &c., are hung in the liquid during the process of electro-deposition. As some solutions have to be worked hot, enamelled iron is generally employed to contain them, as glass would not be sufficiently safe, owing to its liability to fracture by heat, for such a purpose; independently of it and porcelain being bad conductors of heat, if the latter be applied directly to them; and heating by steam would not be admissible, because of the dilution of the solutions that would thus be occasioned. In respect to the metallic connections, of wires, &c., between the batteries, and decomposing troughs, sufficient has been said at p. 275, *ante*, as to size, conductivity, &c.

In preparing metallic objects for all electro-metallurgical processes, it is essential that their surface should be as clean as possible; because, whatever exists on that surface will cause a defect either on the surface of the copy taken from it, or on the exterior electro-plated surface.

Hence a variety of liquids are required, technically called pickling and dipping, the object of which is to cleanse articles submitted to their action. The principle is, to use such an acid or other solution as shall serve to dissolve away the oxide, &c. At p. 284, *ante*, when discussing the operation of amalgamating zinc for battery use, it will be noticed that dilute sulphuric acid answered perfectly well to cleanse the zinc surface. A similar solution will also serve for iron, after the application of the scratch-brush lathe, previously described. Copper, and all articles containing it (such as brass, &c.), require nitric acid, or a mixture of nitric, sulphuric, and hydrochloric acids, with water, into which the articles are to be dipped to cleanse the surface. The exterior will thus be easily cleansed; but deeply in-cut parts or engravings may not be reached by such methods; and, consequently, the assistance of a brush, and some exceedingly fine sand, will be requisite as well as the use of the acid.

In all cases where the acid has been used, as soon as it has performed its office, it should be carefully washed away with abundance of warm water; for if a little be left, a coating of oxide will almost immediately form, especially if the metallic surface be in contact with the atmosphere, and all or most of the preceding labour will become useless.

The extreme value of cleanliness in all electrotyping processes cannot be too strongly insisted on; for without it, in electro-plating and gilding, it will be impossible to cause the adhesion of the precious metals to those that are readily oxidisable. Not only so—the process has such delicacy in its results, that a film caused by the touch of a finger on a polished metallic surface, may be electrotyped so perfectly that every pore may be detected on the surface of the copper copy. In the early days of the electrotype this circumstance was fully appreciated, and sometimes too much so; for on more than one occasion, cleaning was carried to such an extent, that, on copper being deposited on a copper engraved plate, the adhesion became so perfect that it was impossible to separate the two; and, consequently, great loss was sustained in the destruction of the engraver's work.

Occasionally, it is necessary to secure the adhesion of the deposited metal; and for such purposes a solution of mercury is made, by dissolving that metal to saturation in nitric acid, and diluting the consequent solution very largely with water; the proportions being one ounce of mercury dissolved in nitric acid, diluted with three times its bulk of distilled water, and the solution so obtained being diluted for use with a gallon of water. Or, if preferred, the preceding nitrate may be converted into a cyanide, by adding to it, diluted, a solution of cyanide of potassium so long as a precipitate falls. This is collected, washed, and then dissolved in a strong solution of cyanide of potassium, and the resulting solution diluted with a gallon of water. A coating of the inferior metals with this solution, judiciously applied, ensures the subsequent adhesion of the silver in the electro-plating process.

Moulding.—The question of a suitable material for moulds for the purpose of taking copies of solid objects, is one that has had much discussion, and given rise to a great variety of recipes. Common sense teaches the object that is to be kept in mind; for whatever the purpose that is needed, sharpness of outline is of the most importance—first, as regards an impression obtained; and next, that of an ability to sustain subsequent operations, by which, if the material be too soft, the best primary results may be injured. For example, by careful usage, the best white wax, from its fluidity at low temperatures, is a substance most highly capable of giving an excellent impression; and in cold weather, the mould taken will well stand the subsequent operation of brushing with black-lead: but in hot weather, the wax softens so much, that to obtain a really good impression, except with careful regard to temperature, is barely possible. It is, consequently, evident that divers modifications must be made in the choice of the substance by means of which we may hope to obtain, by the use of any material, good, complete, or exact copies or moulds of a work of art. It must be here distinctly understood that we now chiefly, if not solely, refer to copies obtained by the deposition of copper by electrochemical action.

Perhaps a slight historical view of the whole subject may assist many of our readers. When the art of the electrotype first became popular, two works were issued—one by Mr. Smee (already mentioned at p. 266, *ante*), and another by Mr. Walker, now, or lately, the manager of the telegraphic system of the South-Eastern Railway, but then better known as the able secretary of the London Electrical Society, which has ranked amongst its members some of the most eminent electricians of the day. To Mr. Walker's work on *Electrotype Manipulation*, published by Knight and Sons, of Foster Lane, London, we were indebted for many of the earliest steps in our progress in the art.

We have already stated, at an earlier page, that *fusible metal* was the first material employed to obtain a mould or copy of medals, or medallions, which were the first subjects of electrotyping. Mr. Walker thus gives a recipe for pursuing the process involved in that method:—

"*Fusible Metal.*—This is an alloy consisting of bismuth, tin, and lead; it melts at a low temperature, a few degrees below that of boiling water; and has been used as a philosophical toy [or, more properly, as a material of one], in the form of spoons, which melt in hot tea. For this purpose it generally contains a small portion of mercury. Since the discovery of the electrotype, it has been prepared for that purpose without mercury; and may be obtained at the philosophical instrument-maker's."

At the time Mr. Walker wrote this, the fusible metal was almost the only material employed for the purpose suggested; and presuming the impossibility of some of his readers obtaining the alloy above named, he gives the following recipe for its manufacture:—"The proportion of the different ingredients in a pound of this

alloy, are—eight ounces of bismuth, three ounces of tin [in rod or bar, *not* tinned iron, usually sold as tin], and five ounces of lead. These should be melted on the fire [an ordinary one], no longer than is necessary to produce complete liquefaction [or melting] of the several ingredients. When melted, pour the metal on a stone or marble slab in drops." The object of this is to divide the particles of the alloy in such a manner that, in subsequent operations, the mixture of the ingredient metals may be as perfect as possible. "Then, after having *rubbed the ladle clean* [to prevent the possible presence of oxide of any of the metals that have been used] with coarse paper, return the pieces of metal [or alloy], re-melt them, and pour them out in drops as before. A third melting will ensure the ingredients [having] been well mixed. There is very little fear of failing in converting this metal into moulds if the ladle be rubbed between each melting [for reasons aforesaid], and if the metal be removed from the fire at the instant it is melted. The former ensures a bright surface to the mould; and the latter preserves the alloy from change by oxidation." He adds :—

"*To make a mould in fusible metal,* melt some [of the alloy above described] in a clean iron ladle, and pour it on a slab ; then, from the height of two or three inches, drop on it a medal [coin, or other metallic engraved object] to be copied, taking care that the medal [&c.] is *cold.* In a few seconds the metal [alloy] will be solid, and may be placed to cool ; when it is cold, either with or without a few slight taps, the two [alloy and coin] will separate ; and, if proper care have been taken, an exceedingly sharp mould will be obtained."

This method was one of the first that we followed, and, as already stated in our historical account of the art of electrotyping, was primarily adopted ; because, whilst a tolerably accurate impression could be thus obtained, at the same time the surface, being metallic, was an excellent conductor. In the absence of a knowledge of black-lead as a superficial conductor —the use of which was first suggested by Mr. Murray, as stated at p. 265, *ante*—only metallic surfaces could be then employed. All that portion of the copy in the alloy that was not desired to be coated, was covered with a solution of sealing-wax, or shell-lac in spirits of wine ; and this was allowed to dry. Consequently, on such portions as were thus treated, a non-conducting substance prevented the deposition of metal when the mould was placed under electro-chemical action. Of course, a conducting wire was affixed to the mould, to attach it either to the zinc of the single cell arrangement, or the zinc of the battery, if the separate decomposition trough was employed.

But it is evident that the uses of the fusible metal must have been necessarily limited. Sulphur was advocated as a substitute ; but its action, in a melted state, on either copper or silver, afforded insuperable objections to its general employment. White wax, we believe, next presented itself ; its surface being made conducting by being rubbed over with the best black-lead in powder, by means of a fine brush. Mr. Walker's early instructions, given as follows, are still attended to. He remarks, to form—

"*Wax Moulds.*—The manipulation with this material is very simple. The wax employed is the common white wax, or the ends of wax candles. It is to be melted in an earthen pipkin, and kept on the fire [for] a few minutes after it is well melted. The medal to be copied should be made warm ; the warmer the better (the object being to prevent the sudden chill of the wax when poured on). It is then surrounded with a rim, composed of a riband of pasteboard. The end of this may be conveniently secured by a small cleft-stick. The surface of the medal should then be very slightly covered with olive oil. The hot wax is then [to be] poured on. It will require five or six hours to become sufficiently cold for removal."

Since Mr. Walker penned the above remarks, and as we shall subsequently notice, a great number of recipes for mould-materials have been given and patented. But within a few minutes of our own pages being written, and nearly forty years since Mr. Walker stated the preceding views, we have seen a copper electrotype, made from a mould, as above described, that equals, in sharpness and perfection of outline, any that have yet been presented to our notice. In our own practice we have *never* met with any material equal to good white wax, as a matrix or mould for electrotyping purposes, where copper is to be deposited, provided great care be taken to use the best black-lead as a conducting material ; and our experience has not been limited in the matter.

For many reasons, at the time Mr. Walker wrote his first instructions in the art of moulding for the purpose of obtaining good copper copies of an object, other materials were sought for in place of white wax ; and he thus describes—

"*Stearine Moulds.*—There will be, at times, a difficulty in removing wax moulds from medals with elaborated work. If this be the case, boiling water should be poured into a cup, or any vessel smaller than the object [he says 'medal'] ; and the medal, with the wax upward, should be placed on this. The sudden influx of heat will expand the medal, and generally cause the separation without further difficulty. This will occur in a few seconds. To avoid this trouble and uncertainty, stearine will be found a far better substance than wax. It very rarely adheres to the metal, especially if the latter, when practicable, have been previously rubbed with black-lead."

One of the best objects of the kind—that is, a substance that can be melted at a low temperature—is the modern solid paraffin, as now sold in the form of the *best* "gas candles." With proper management it may be made to afford an excellent copy of most objects, and be made conducting by the usual application of black-lead. It certainly requires some care, and, consequently, a little experience ; but, at the same time, is most readily manipulated for a great

variety of objects, in a similar manner to that already described for white wax.

Of course a complete conducting surface must be made between the wire proceeding from the zinc of the battery cell, and the surface of an otherwise non-conducting mould; and no matter what form the object may be in respect to the mould, the same principle and practice are involved. For example, in the following cut, *a*

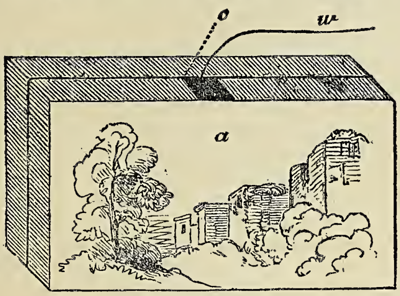


Fig. 176.—Mould for Electrotyping.

represents a wax or other non-conducting surface. It is to be carefully black-leaded over on all parts that are to be covered with metal. *w* is a wire connected with the zinc of the battery. Generally it is best that it should encircle the mould, for the sake of giving it firm hold; but, in any case, a conducting surface should be effected by black-leading the mould in such a manner that the portion *c* of the wire should have direct communication, electrically, with the whole of *a*; that is, the black-leaded surface of the mould. This is to be effected by black-leading from the mould to *c*, so that such a surface should be completely continuous. In certain cases, if *a* be very large, a bunch of fine wires is connected with *c*, and so spread over the black-leaded surface, *a*, as to touch it in many parts; and thus the generality of electro-conducting surfaces are maintained. But on this point, as on other methods adopted for a similar purpose, we shall have to speak more fully hereafter, for their name and number are *legion*.

As regards materials for moulds, we next quote Mr. Gore. He says—"The electro-depositor who includes in his business not only the ordinary electro-plating, but also the manufacture of works of art by deposition, requires a number of substances for moulding, and preparing the surface of the moulds to receive a deposit. For moulding ordinary metal objects, he often uses gutta-percha, or a composition consisting of equal parts of white wax and spermaceti; but one of the best substances we have used for this purpose, has been a composition of our own, consisting of two parts of gutta-percha, and one part of Jeffery's marine glue: the glue is cut up into small pieces, and melted at a gentle heat in an iron ladle; the gutta-percha, also cut very small, is then added, and the mixture constantly and vigorously stirred at a gentle heat until the two are thoroughly incorporated. This substance possesses several important advantages over gutta-percha alone, as a moulding material; it is softer when heated, and takes a sharper impression; it contracts more in cooling, and is, therefore, more easily removed from the original; and in taking the black-lead it is very superior to gutta-percha. With ordinary care, many copies may be taken by deposition off one of these moulds; we have taken upwards of ten from one of them."

In respect to elastic moulding substances, he observes as follows:—

"When the objects to be copied are much under-cut, or when we wish to take a mould of a bust, all in one piece, elastic moulding composition is required. The best, and almost the only one used, is composed of four parts of best Russian glue and one part of treacle. The glue should be broken into small pieces, and soaked for one or two hours, or until it is quite soft, in sufficient *cold* water to cover it: when it is soft the superfluous water is to be thrown away, and the glue, together with the treacle, is to be heated in a common glue-pot, like ordinary glue, to nearly a boiling heat, and stirred until the two substances are thoroughly mixed. The use of the treacle is to prevent the mould drying and shrinking too rapidly."

In using such a moulding, the same authority recommends the following in practice, especially in the case of the model being much under-cut—a phrase that will be perfectly understood by the practical engraver. He thus advises in respect to moulding and copying works of art, and for elastic moulding, as hereafter separately mentioned:—

"The electrotypist who includes in his business the multiplication of works of art, as well as the simple plating of metal articles, will require a knowledge of the art of moulding. To copy both sides of a metallic coin or medal in the mixture of gutta-percha and marine glue [just described], take a strip of thin sheet copper, brass, or tinned iron, about an inch wide; wind it closely round the edge of the medal, and solder its ends together. Wipe the medal, and take two balls of the composition, quite hot and soft, and press them simultaneously against the two faces of the medal, working the material from the centre towards the circumference, to exclude bubbles of air. Place two thick plates of cold metal, one on each side, and gradually screw up the whole in a vice, or screw-press [or, in our experience, the hydraulic press under careful management], gently at first, but increasing the pressure to a high degree as the materials become hard. When it is quite cold, which will be in about two hours, the two copies may be easily removed from the original by inserting the end of a gimblet [or bradawl] in their backs, and drawing them out. They are easily removed, because the composition slightly contracts in cooling. They will present fine impressions of the original, and be perfectly free from air-bubbles when the operation has been carefully performed."

In reference to elastic moulding, the same authority observes—"If the medallion be under-cut, it must be copied in elastic moulding [just previously described], thus:—Encircle its edge by means of a strip of stout paper, and pour off

the mixture upon its surface, quite hot, and of the consistency of treacle, to the depth of half an inch or more, according to the size of the object, and the depth of its hollow parts; brushing its surface, beneath the liquid, with a brush having fine and long hairs, to remove all air-bubbles. Allow the mixture to remain until it is quite firm, which will require from two to twenty-four hours, depending on its bulk. Then take off the paper, and remove the mould very gently, carefully stretching and drawing it, at the same time, in the direction of the overhanging parts, to prevent injury. Should the object to be copied be a hollow metallic bust, proceed as follows:—Partly fill it with sand, to make it heavy, and thus to prevent its rising in the liquid; cover its opening by sticking a piece of millboard strongly over it. Then place the bust in the centre of a cylindrical and tapering vessel, a few inches deeper and wider than itself, and pour the melted composition in steadily, until it rises to a few inches above the top of the head, tapping the bust, and inclining the outer vessel, to facilitate the escape of air-bubbles. When the composition is quite firm (which to effect will require about twenty-four hours), it may easily be removed from the vessel by shaking, the vessel having been previously well oiled. The mould may then be removed from the bust, previously having marked, on its lower end, the position of the face, by passing a knife carefully up the back of the bust, nearly up to the crown of the head, and opening the elastic mould with the hands, whilst an assistant lifts out the bust. If the original be made of plaster of Paris, or other such substance, it should be saturated superficially with oil, to prevent the melted composition adhering to it."

A great variety of substances has been recommended as a material for moulds; but it is evident to the most inexperienced reader, that the material employed must, in a majority of cases, be specially adapted to the object required. Thus wax, or its analogues, that we have strongly recommended, for many reasons, at p. 286, *ante*, would be perfectly inadmissible in an attempt, at least in most instances, to obtain a copy of an engraved plate, because the undercutting—that is, the running-in of the graver or acid below the vertical-line-depth of the engraving in a horizontal direction—would render it impossible to detach the mould from the original without injury to the former. We have tried, with considerable success in certain cases, the following plan in multiplying copper engraved plates:—Let a piece of good soft sheet lead be well and truly planed by a metal-planing machine. Place this over the engraved copper plate, and use the hydraulic press to force the lead into the engraved lines. By a little care, the lead reverse copy may be removed without great detriment to the fineness of the copy; and the softness of the lead at once allows of an easy correction, by the engraver, of any destruction of outline. The lead plate being, of course, conducting, is readily copied by the ordinary electrotype processes in copper.

Some years ago, Mr. Alexander Parkes patented the following method, by which an elastic substance and a conducting surface were simultaneously attained. His plan was as follows:—First, "the phosphorus solution: to make nearly three ounces of which, melt 64 grains of beeswax or tallow; then dissolve 8 grains of india-rubber, cut up very small, in 160 grains of bisulphide of carbon; and when it is dissolved, add to it very carefully (as it is highly inflammable) the melted wax, and shake the mixture thoroughly. Then dissolve 64 grains of phosphorus in 960 grains (about $2\frac{1}{4}$ ounces) of bisulphide of carbon, and add to it 80 grains of spirit of turpentine, and 64 grains of asphalte in fine powder: when dissolved, add this solution to the previous one of india-rubber and wax, and thoroughly mix them by shaking.—The silver solution: to make twenty ounces (one pint) of this liquid, dissolve about 18 or 19 grains of pure silver in about 20 or 25 grains of the strongest nitric acid, and dilute it to the required volume with distilled water.—The gold solution: to make 20 ounces of which, dissolve about 5 or 6 grains of pure gold [that is, entirely free from copper, &c.] in about 20 or 25 grains of a hot mixture of 1 measure of [strong] nitric acid, and about 2 or 3 measures of hydrochloric acid. When dissolved, dilute the solution with 20 ounces [an imperial pint] of *distilled* water.

"The same patentee includes in his patent a phosphorus moulding composition, by the use of which the immersion in a phosphorus solution is dispensed with, the moulds themselves containing the required amount of phosphorus. To make about one pound of this composition, melt together half a pound each of wax and deers' fat; then dissolve about 19 or 20 grains of phosphorus in about 300 grains of bisulphide of carbon. Keep the wax mixture barely melted, and add the phosphorus solution slowly to it, and with brisk stirring of the fat, pouring it in at the bottom of the melted mixture by a vessel [a funnel] with a long spout to prevent its inflaming." The solution of phosphorus in bisulphide of carbon should not be allowed to fall on any inflammable matter, because it would speedily cause its ignition, and, consequently, is a most dangerous liquid to deal with.

As previously intimated, the variety of substances that have been employed for moulding purposes is very great; and, consequently, many others might be described. The chief materials, however, that are usually employed have been noticed; and the selection of a suitable one for any special purpose must be left to the judgment of the operator.

Depositing Liquids.

The choice of depositing liquids is, theoretically, of great extent; but, practically, limited, simply because the conditions that must be observed to obtain success, impose the necessity of the observance of certain principles, to fulfil the requirements of which, in all cases, has generally been difficult.

The authority whom we have already frequently quoted (Mr. Gore), remarks thus:—

"The following rules should be observed in selecting a suitable depositing liquid for the battery process:—

"1st. It should act strongly upon the anode, and hold abundance of metal in solution.

"2nd. It should possess good electrical conducting power.

"3rd. It should yield its metal freely, and in a reguline state. [See the laws enunciated by Mr. Smee, given at p. 266, *ante.*]

"4th. It should not act chemically to any extent upon the base metals [that is, such as copper, lead, zinc, iron, &c.], because it is those that we generally wish to coat, and chemical action on them would endanger the adhesion of the deposited metal.

"5th. It should not decompose by contact with the atmosphere; nor should light influence it in such a way as to injure it for depositing purposes.

"6th. It is better if it do not evolve gas at the surface of the receiving article [or cathode] whilst depositing [is proceeding], because that generally indicates a waste of battery power, attended by oxidation of the liquid."

It is evident that, in many cases, great difficulty may occur in selecting a good depositing liquid for a metal; and the first experimentalists had, consequently, great obstacles to battle with. A solution of sulphate of copper, with free acid, fulfils all the six conditions named above; and hence doubtless it was that, as the deposition of copper was the first step in the art of electro-metallurgy, the latter progressed so rapidly in its early stages. Copper deposition, of the most satisfactory character, can scarcely be avoided, by ordinary care, with an acid solution of the sulphate, even in the most unpractised hands.

Not so, however, with the precious metals; and, indeed, with others we shall name. It could have been expected, that the fact of copper being so readily deposited, would lead to attempts to deposit gold and silver. The early methods, and those adopted until the discovery of the electrotype, were difficult, uncertain, and expensive. If only a slight superficial coating were required, the article to be plated or gilded was dipped in either a solution of nitrate of silver, or rubbed with various mixtures containing that metal; and in respect to a similar process in gilding, a solution of gold in nitro-hydrochloric acid was employed, adding ether, which, taking up the gold, deposited that metal on the inferior ones when the latter were dipped into it.

Next in order and durability, was that of making an amalgam of gold or silver by dissolving these metals respectively in mercury. The article to be coated was then rubbed with either of these amalgams, and exposed to heat, by which the mercury was driven off, and the precious metal left on the surface of the inferior. A still more durable plan—say in the case of silver, first—was that of soldering a plate of the latter metal on one of copper. This double plate was then extended by passing it between steel rollers, held together by great pressure; and thus a sheet of plated copper was formed, having one external surface of silver. But, in the course of time, this wore off, and left the hideous nakedness that characterised old Sheffield plate, some parts presenting a copper, and others a silver surface; but the article became valueless, and unfit for use; and, in that condition, only could be "stripped" of its silver by the refiner, or be temporarily coated with a thin film of the metal by water-gilding, or the amalgam method above described; or, still more temporarily, by silver or gold "washes," that stood little or no wear.

It was, therefore, of the utmost importance to discover some solution by means of which the precious metals could be deposited in a reguline state. The nitrate of silver, and the chloride of gold, both failed signally; for, in each case, the acid or chlorine set free was antagonistic to the fourth condition just enunciated—namely, they both rapidly acted on, to a great extent, the base metals which it was desired to be coated. Fortunately, it was discovered that the cyanides of silver and gold, dissolved in an excess of cyanide of potassium, afforded solutions that, like the sulphate of copper, fulfilled, with ordinary precautions, all the conditions previously stated; and, consequently, at the present day, the deposition of those metals—silver and gold—is effected with the greatest certainty, precision, and ease. Similarly, the difficulties in depositing other metals, as iron, &c., have been got over by modifications in the solutions early applied, or by the discovery of new methods.

For a general view of the *method of making depositing solutions*, without entering into exact details (that will be presently dealt with), we are indebted to the authority last quoted; who remarks—

"This may be done by two methods, the one called *Chemical*, and the other the *Battery process.*

"The chemical process consists in mixing the various ingredients by the usual means, and in suitable proportions, to form the liquids. For instance—1st. The ordinary sulphate of copper solution is prepared by dissolving a certain proportion of commercial sulphate of copper in water, and adding to it a definite quantity of sulphuric acid, to afford *free* acid; and, 2nd. To form the ordinary cyanide of silver and potassium plating liquid, silver is dissolved in dilute nitric acid; the solution of nitrate of silver formed is precipitated by addition of a solution of cyanide of potassium; the white precipitate of cyanide of silver is washed, and then added, as much of it as will dissolve, to a solution of cyanide of potassium; after this, an additional portion of cyanide of potassium is added, to afford *free* cyanide"—or, more properly available, free cyanogen.

It is evident, therefore, by the preceding processes, described only illustratively, and not in detail, that the operator avails himself solely of ordinary chemical affinities, and the manipulations of solution, precipitating, and washing; and that no apparent electrical cause is put into work.

"The *battery* process consists in taking some water, and dissolving in it a certain proportion of acid or salt, as the case may be; then placing a large anode of the given metal at the lower part of the liquid, and a small [short] bright cathode at the upper part, and, if necessary, applying heat. Connection is to be made with a suitable battery, until the required quantity of metal is dissolved, which is indicated by the cathode receiving a good deposit. In making gold solutions, the cathode is generally placed in a small porous cell, filled with the same liquid, and immersed nearly to its edge in the outer liquid; and, by transferring the cathode occasionally to the gold solution, and observing if it receive a good deposit, we may know that sufficient metal is dissolved; the liquid of the cell may then be added to the outer solution.

"If it be wished to make sulphate of copper solution by this method (which we should not advise, however, the sulphate salt being so cheap), take the same quantity of water as we prescribed for the chemical method, and add to it as much acid as was contained in the salt of copper [see the chemical constitution of *Copper Sulphate*, given at p.270. *ante*, as a guide for the quantity of acid], with the free acid as before, and then pass a current from a battery of one or two pairs by a large anode, and small cathode, until sufficient metal is dissolved.

"If it be desired to make some cyanide of silver and potassium solution by this method, which is sometimes done, take the same proportions of water, cyanide of potassium, and free cyanide as in the chemical process, and pass the electric current by a large [pure] silver anode, until the same proportion of silver is dissolved as required by the chemical method." For the constitution of the cyanide of silver, see the page just referred to.

We must here point out the difference of economy in the two methods—the chemical and the battery processes. When solutions are made by the chemical plan, the cost of the manufacture of the salt is paid for at the time of its purchase—as, for example, in buying the sulphate of copper, or the nitrate of silver; the same observation applying also even to the preparation of the latter salt by the operator; for he has to pay for his nitric acid and silver, simply having to dissolve the latter in the former. But in the battery process he has to employ a force that costs money. Thus, if he make his own sulphate of copper solution by it, besides the expense of acid and copper, *must be added that of the electromotive* force inducing the solution. Now we have already shown, at p. 280, *ante*, that for each 32 grains of copper dissolved or deposited by electro-chemical action, 32 grains of zinc (both quantities being in round numbers, for simplicity's sake) are expended or dissolved in each cell of the battery causing the solution. If two cells are employed, then each 32 grains of copper will cost 64 of zinc; and so on: an increased cost is incurred according to the number of cells employed. Consequently, as shown at p. 274, the cost of depositing the copper may be raised—taking the comparative commercial price of the two metals—from one-fourth to half, two-thirds, &c., its value in the expense of the zinc required by the battery, independent of the cost of the acid used to excite the latter. If three cells be employed to make a copper depositing solution, the cost of the zinc consumed will equal the value of the copper dissolved; and hence, practically, the cost of the latter will be doubled.

But if we adopt the battery process for silver solution-making, the extra cost becomes trivial. In the first place, the value of zinc to silver is less than as 1 to 250; and again, referring to p. 269, *ante*, it will be seen—bearing in mind that chemical and electro-chemical equivalents are identical—that, for every 32·6 grains of zinc dissolved in each cell of a battery, 108·0 grains of silver will be either dissolved or deposited. Consequently, whilst the cost of making a copper depositing solution by the battery process equals $\frac{1}{4}$th of the cost of the copper at least, the cost of the battery process is only about $\frac{1}{750}$th of the value of the silver dissolved. The much greater value of gold, and its high equivalent (197·0), render the cost of the battery process, in making a gold solution, trifling.

Herein we see the great value that a knowledge of scientific principles must be to the electro-metallurgist in controlling the cost of his operations, and also in guiding him safely and surely in each step of his progress. As previously remarked, there are few branches of applied science, in manufacturing industry, that are so exact and perfect in their transference of principles to practice.

Still continuing general remarks on depositing solutions, we may next turn to consider how any solution may be tested as to its suitability for depositing purposes. It must evidently fulfil all the conditions detailed at p. 289, *ante*—namely, it must dissolve the anode freely; be a good conductor; yield metal freely; not act more than possible on the anode; not be liable to spontaneous decomposition, action of the oxygen of the air, or light; and, lastly, should not permit of the evolution of gas at the surface of the cathode, or object on which the metal is to be deposited. The following plan has been suggested for the purpose of testing solutions generally.

"To test a depositing liquid, pass a current of electricity from about two cells of Smee's battery, with a suitable clean anode of the metal in solution, of proper size, and a clean piece of iron, brass, or copper, of about the same size, to receive a deposit, observing how much gas is evolved in the battery. If the deposit appear quickly, and of a bright and proper colour, and if it adhere to the metal, the cathode evolving gas from its surface, and the anode dissolving freely, cleanly, and without escape of gas, work it at intervals, keeping it exposed to light and air. Observe if it continue to work well; or whether, on the contrary, it shows a decrease of conductibility; deposits a sediment; or if the anode become covered with an insoluble crust, which may arise from deficiency of free acid, or from impurities of the metal.

"If but little gas be evolved in the battery, the liquid in the decomposing cell is a bad conductor, and will neither dissolve nor deposit the metal freely at that temperature; or it is deficient in free acid or free salt.

"If the deposited metal be of a bad colour, either the battery is too strong, the receiving article too small, or the liquid is incapable of yielding good metal.

"If the immersed metal or article be coated by simple immersion, without the aid of the battery, it shows that, to adapt the liquid to articles made of that particular metal or alloy, they must receive some previous preparation, in order to make the deposit adhere.

"If it deposit a sediment, or alter in conductibility by exposure to air and light, the probability is, that those influences alter either its chemical composition, or the arrangement of its particles.

"If it evolve gas at the receiving surface [or cathode] during deposition, it shows either that there is too much battery power; too little metal in solution; too much *free* acid; or that it is a wasteful liquid, in which one part only of the current is employed in depositing metal; whilst another part of it is employed in evolving gas, and oxidating the liquid."

The preceding remarks are of great value to the practical man. From some years' attention to the advice thus given, we have no hesitation in saying, that nearly every difficulty that we have met with, is, more or less, touched on in the observations; and, at the same time, remedies of such become at once evident by the suggestion of other modes of procedure than those that fail, the causes of failure being plainly pointed out.

In attempting the deposition of nickel and tin, we have especially found them of value. These two metals, so far as our experience has taught us, are amongst the most troublesome that can be managed. Many recipes have been given for their successful deposition, to which further allusion will be made hereafter; but, as a rule, every solution that we have tried, more or less, contravenes the six conditions given at p. 289, *ante*, as requisite to form a thoroughly effective depositing liquid; and, in attempting to deal with them successfully, we found undoubted reason to follow the suggestions involved in, and arising from, the observations just quoted. But these difficulties have been got over.

Of course, the present remarks are applicable to *all* solutions of a metallic nature that are employed in metallurgy. At succeeding pages we shall enter into an inquiry and description of them in detail, as applicable to each, and suitable for special metals; but still the preceding remarks, &c., will be of equal application in all cases that may arise.

Mr. Gore also gives the following general directions for testing solutions intended to deposit alloys.

"With solutions in which alloys are to be deposited, the most important condition is, that neither of the metals to be deposited should be electro-positive to each other in that liquid [see *ante*, p. 274, in respect to electro-positive and electro-negative metals]. This is best tested by taking a wire of each metal, connecting them with a galvanometer, and, simultaneously, immersing their free ends in the liquid. If either be electro-positive, the needle of the instrument will be deflected, and the direction of the deflection will indicate the amount of their electric difference in that liquid. It may also be tested by immersing a wire of each metal (not in mutual contact) in the liquid: if either become coated with metal in an hour, that one is positive; but if neither become coated in six hours, there is no perceptible electric difference between them."

After stating a variety of experiments, which tend to prove, "that if a liquid contain two metals in solution, and a wire or other piece each of those metals be immersed in the liquid, and one becomes covered with a deposit of metal, while the other does not, the one so covered is electro-positive to the other in that liquid, and the solution will only yield the same metal that is deposited by simple immersion"—Mr. Gore goes on to remark—

"With regard to the influence exercised by the proportions of the ingredients of the liquid, and the strength of the current, we may observe, that if a liquid contain several metals dissolved in equal quantities, and only one is being deposited by the passage of a weak current, a considerable increase in the strength of the current will cause a portion of the next more positive metal to be deposited along with the less positive one; but this alloy deposit will not be very coherent, because the power required to deposit the second metal in the negative state will be so great as to deposit the first as a soft powder. This holds most true when the difference of electric power [electro-motive force] required is at a maximum. For instance—1st. If small and equal quantities of sulphate of zinc and sulphate of copper are dissolved together in a large quantity of water, and a feeble current be passed through the solution, only reguline copper will be deposited. But if the battery power be considerably increased, either by a greater number or a larger surface of the battery plates, the deposit of copper will cease to be reguline, and zinc will be deposited with it. If the power be still further increased, hydrogen gas will also be evolved at the surface of the deposited metals.

"2nd. If we dissolve a small quantity of sulphate of copper, and a great quantity of sulphate of zinc, in a large quantity of water, and pass a strong current through the solution, copper, zinc, and hydrogen will be set free at the cathode.

"3rd. If we slightly moisten a lump of caustic potash with pure water, and pass a weak electric current through it by platina electrodes, hydrogen alone will be set free at the cathode. But if a very powerful current be employed, potassium also will be deposited.

"In each of these cases we find that, when the current is weak, the least positive of the positive substances is alone deposited; but if

the power be sufficiently increased, and there is only a small proportion of the less positive substances present, the more positive substances, even though they are much more positive, will also be deposited. Thus the weaker affinities are overcome first, and to the greatest extent; the current of electricity exercising its influence first, and in the greatest proportions, upon the salt of the least positive metals."

The preceding remarks, not extended, practically, beyond what is stated in the last few lines of the quotation, are highly valuable and judicious; but, beyond that, require modification. Thus, for example, if a solution of nickel and silver, in an excess of cyanide of potassium, be submitted to electro-decomposition, a series of anomalies will arise. With a silver anode, silver will be deposited; and with a nickel anode, nickel, provided certain precautions be attended to. We have also tried a combined anode of zinc and nickel, and found that the nickel or zinc might be deposited just as the relative ize of the anodes was altered, the largest of either, at the same moment, influencing the deposit. It is evident, in fact, that such a great variety of circumstances is involved in alloy deposition, that it is impossible to predicate the same results to happen in a variety of solutions of different metals, mixed together, and with varying sizes of electrodes. All that we can do is, to assert a general law, as already done at the conclusion of the preceding quotation; and to make specific trials, so as to arrive at definite and special results.

Having thus stated some of the most important points that affect the character of solutions for depositing generally, we next proceed to more practical details in describing some of the best liquids that have been employed or recommended for each different metal, chiefly bearing in view those that are of most practical value, or have been adopted most universally.

Copper Depositing Solutions.—For all practical purposes, in electrotyping, the sulphate is the salt of copper chosen. It is cheap, is a good conductor, and, in fact, combines, as already shown, most of the advantages possessed by any metallic depositing liquid. For the deposition of copper on wax, gutta-percha, or similar moulds, or on a copper surface, the following proportions answer—viz., five, by weight, of sulphate of copper, in crystals, is to be dissolved in about twenty parts, by weight, of water, to which from a fifteenth to a tenth of sulphuric acid has been added. This should be filtered, and it will be ready for use. A less quantity of sulphuric acid may be employed than that above named as a maximum; but this may be left to the judgment of the operator, or the special requirements in view.

From all soluble salts of copper that metal may be deposited, as the nitrate, acetate, chloride, cyanide, &c., the latter being dissolved in excess of cyanide of potassium. A proportion of 65 parts of cyanide to 125 parts of sulphate of copper, has been recommended. The acid solution of sulphate of copper, suitable for all electrotyping purposes in general, will not answer to deposit the metal on others more positive than itself; for, as is well known, the acid would act on zinc and iron. But, according to Mr. Gore, the following method, with iron, is successful:—"To effect an adhesive deposit of copper on iron, a solution, composed of cyanide of copper dissolved in a solution of cyanide of potassium, may be used. It is formed thus:—Dissolve cyanide of copper to saturation in water containing about two pounds of cyanide of potassium to the gallon, and then add about one-eighth more of the cyanide of potassium, to form free cyanide. The liquid is then ready, and should be used at a temperature of about 150° Fah."

The ordinary sulphate depositing liquors work well at common temperatures. Still, the remarks already made at p. 279, *ante*, should be borne in mind in regard to temperature; for, as there shown, the conducting power and ready action of a sulphate of copper solution rapidly diminish with a decreasing temperature, whilst they increase with a raised one.

Frequently, for reasons already named, the specific of a copper solution will gradually vary, increasing downwards in a deep or large trough. This will cause inequality of deposition, and, occasionally, some inconvenience. Usually, recourse is had to stirring this and other depositing solutions; but another evil is brought into play. The sediment that generally falls down in them all, with dust and dirt that, despite all care, will enter a trough, are also stirred up, and may fall on the face of the receiving plate, causing an injury to its surface. Some years ago we adopted a very simple plan—not for electro-metallurgical processes certainly; but it is applicable to them. The object kept in view was, to cause a constant, but imperceptible, set of currents of liquid rising in the liquor, so that uniformity of specific gravity could be maintained invariably. We effected this by passing, horizontally, at the bottom of the trough holding the liquid, a metal pipe fixed water-tight in the two ends of the trough, and allowing steam to pass gently through the pipe. This, very slightly, and under instant control, heated the lower portion of the liquid. Also, by convection, it carried up the cold liquid in warm currents, that, arriving at the top, became cooled, and gradually descended, again to rise on becoming freshly heated. In electro-copper deposition, such a pipe should be made of copper, and had best be first slightly coated, externally, with a coat by the battery process. By this plan the brazing of the pipe is completely covered with pure copper, and no danger of local action, which might otherwise destroy the pipe, could arise.

This simple and effective method of equalising both the specific gravity and the temperature of a liquid, is illustrated by the following experiment:—Pour into a tall, thin glass jar as much of saturated solution of sulphate of copper as will occupy a fourth of its capacity. On the top of the solution place a piece of paper. Then, by means of a funnel, the stem of which nearly touches the paper, fill the glass jar with cold river or other plain water. The paper is simply

intended to break the fall of the water, and keep it from mixing with the copper solution. If the whole be properly conducted, the water will swim at the top, unmixed with the copper solution. If the glass jar be next transferred to a large deep dish, and the latter be filled with hot water, it will be soon noticed that a succession of upward currents will take place, that will carry the heated copper solution quite through the cold water, and, eventually, cause a mixture of the two. On precisely the same principle is the plan that we have proposed for equalising the specific gravity and temperature of depositing liquids. It is scarcely needful to add, that the exterior of the pipe exposed in the depositing liquid should be of the same metal; that is, a silver exterior for a plating solution, and so on—a matter easily effected by depositing on a copper pipe the metal required, by means of the battery process.

Iron Solutions.—Numerous methods have been suggested for depositing iron from solutions. It may be reduced from the protosulphate or the protochloride: a battery solution is made by using an anode of iron in a solution of sal-ammoniac, or other salts of ammonia. Mr. Gore states that he has deposited it from an aqueous solution of ferrate of potash; that is, potash united with ferric acid that contains iron in a high state of oxidation. He adds—"It may be formed either by igniting peroxide of iron [to make which, see p. 273, *ante*] for some minutes with caustic potash and saltpetre; or make a very strong solution of caustic potash, immerse it in a large iron or steel anode, and a small copper or platina cathode, and pass a strong current from fifteen or twenty pairs of Smee's batteries through it, until it acquires a deep amethyst or purple colour. By that time the cathode will have obtained a coating of iron, which will be in the state of a dark gray powder if the power have been too great; or it will have the appearance of white cast-iron, or intermediate between that and the appearance of reguline deposited zinc, if the power have been sufficiently adjusted. This solution rapidly deposes without any very apparent cause, becoming colourless, and depositing all its metal, in the state of peroxide, at the bottom of the vessel. Iron may very easily be deposited from its sulphate thus:—Dissolve a little crystallised sulphate of iron in water, adding a few drops of sulphuric acid to the solution: one cell of Smee's battery may be used to deposit the iron upon copper or brass. The metal, in this pure state, has a very bright and beautiful silvery appearance. An aqueous solution of cyanide of potassium is a very bad conductor with an iron anode, even if it be maintained hot."

We have tried most of the preceding methods, with but limited success; and, in fact, till a lucky thought struck M. Joubert, it would have been difficult to have found any inducement to persevere in the attempt to reduce metallic iron on any metal surface; for iron is so exceedingly cheap, and reducible to any conceivable form, fineness, or thinness.

But M. Joubert conceived the idea of protecting engraved copper plates by coating them with iron, in such a manner that, whilst the originals would, if electrotypes, have become deteriorated on giving 250 to 400 impressions on paper, and if the ordinary rolled copper plates, after affording from 700 to 1,000—by his method an almost infinite number of impressions may be obtained. And as soon as the iron coating has been worn away, it can be restored at a trifling expense, causing the plate to become equal to a newly-engraved one in nearly every respect. Indeed, his plan renders, practically, copper plates more durable than an original one of steel; and hence the difficulty of using electro-copies of engraved plates, arising from softness, is entirely obviated.

The following extracts from a paper read by M. Joubert before the Society of Arts, shortly after he had patented his process, gives an account of the method he pursued, and the results he attained:—

"I have myself had the advantage of co-operating with M. Garnier in the development of the invention, the principles of which I shall now proceed to describe.

"If the two wires of a galvanic battery be plunged separately into a solution of iron, having ammonia for its basis, the wire of the positive pole is immediately acted upon, while that of the negative pole receives a deposit of the metal of the solution: this is the principle of the process which we have named 'acierage.'

"The operation takes place in this way:—By placing at the positive pole a plate or sheet of iron, and immersing it in a proper iron solution, the metal will be dissolved under the action of the battery, and will form hydrochlorate of iron, which, being combined with the hydrochlorate of ammonia of the solution, will become a bichloride of ammonium and iron: if a copper plate be placed at the opposite pole, and likewise immersed, the solution being properly saturated, a deposit of iron, bright and perfectly smooth, is thrown upon the copper plate, from this principle—

"Water being composed of hydrogen and oxygen;

"Sal-ammoniac being composed of—

"1st. Hydrochloric acid, containing chlorine and hydrogen;

"2nd Ammonia, containing hydrogen, nitrogen, and oxygen;

"The water is decomposed under the galvanic action, and the oxygen fixes itself on the iron plate, forming an oxide of iron; the hydrochloric acid of the solution acting upon this oxide, forms a hydrochlorate of iron, whilst the hydrogen precipitates itself upon the plate of the negative pole, and, unable to combine with it, comes up to the surface of the solution in bubbles.

"My invention has for its object certain means of preparing printing-surfaces, whether for intaglio or surface-printing, so as to give them the property of yielding a considerably greater number of impressions than they are capable of doing in their ordinary or natural state. And the invention consists in covering

the printing-surfaces, whether intaglio or relief, and whether of copper or other soft metal, with a very thin and uniform coating of iron, by means of electro-metallurgical processes. The invention is applicable whether the device to be printed from be produced by engraving by hand, or by machinery, or by chemical means, and whether the surface printed from be the original or an electrotype surface produced therefrom. I would remark, that I am aware that it has been before proposed to coat type and stereotypes with a coating of copper, to enable their surfaces to print a larger number of impressions than they otherwise would do; I therefore lay no claim to the general application of a coating of harder metal on to the surface of a softer one; but my claim to invention is confined to the application of a coating of iron, by means of electricity, on to copper, and other metallic printing-surfaces.

"In carrying out the invention, the solutions of iron employed may be varied; and such is the case in respect to the arrangement of the galvanic battery, or other source of electric currents used: I do not, therefore, limit the invention to the means hereinafter described; but I believe they will be found to be the best for the purpose.

"I would further remark, that it is important that a ferric solution should be employed which will not dissolve or corrode the plate intended to be coated; for if it be attempted to use such a solution, though the iron will be precipitated, it will not only be in a non-coherent state, but the engraved surface itself will be liable to be attacked and injured. It may also be remarked, that the coating of iron admits of being removed from a printing-surface of copper without injury to the original plate; hence the original plate may, after being coated and used for some time, have the worn coating removed, and then be re-covered with an iron coating, as often as may be required; and if care be taken to remove the coating of iron before it has been entirely worn away, the engraved copper or other plate may be made to print a vast number of impressions, and yet remain in the original state it was in when it left the hands of the engraver, or was otherwise first produced; the only limit appears to be in the gradual change which takes place in the body of the printing-surface, by the compression to which it is subjected in the process of printing. Heretofore, in respect to plates engraved in intaglio, if of steel, they each yield, on the average, about 3,000 impressions without re-touching: if of copper, they each yield, on an average, not more than 800 without re-touching; whilst electro-casts of copper, obtained from the originals, will not, on an average, each yield even 200 impressions without re-touching; in fact, such printing-surfaces are so easily worn, that, after the first 100 or 150 impressions, there is a considerable deterioration in the quality of the work produced. Therefore, for the supply of the number of impressions often required by art associations and others, it has been found necessary to multiply the electro-casts very considerably. In such cases the invention is applicable with considerable advantage; for I find that an electro-plate, 40 × 22 inches, covered or coated with iron, has yielded 2,000 impressions without its being necessary to remove and renew the iron coating, there being no perceptible difference between the first and last impression, the work on the plate appearing not to have suffered in the slightest degree. Hence, in future, by the application of the invention, it will only be necessary to multiply electro-casts to such an extent as may be necessary to ensure the production of prints or impressions, with the requisite speed, on paper, calico, or other fabrics. At the same time, an original engraving on copper would become, when treated according to the invention, more lasting than if engraved on steel. Although original surfaces, engraved in relief, and also electro and other casts, taken from them, yield a considerably greater number of impressions than those I have mentioned as obtained from plates engraved in intaglio (to which the invention has not been applied), nevertheless the invention is applicable, with great advantage, to such relief printing-surfaces, whether of copper or other soft metal; for if they be coated with iron, according to the invention, they will yield almost an indefinite number of impressions, provided the iron surface be renewed as often as may be necessary, and the printing surfaces be again re-coated.

"In carrying out the invention, I prefer to use that modification of Grove's battery known as Bunsen's; and I do so because it is desirable to have what is called an intensity arrangement. The trough I use for containing the solution of iron, in which the engraved printing-surface is to be immersed in order to be coated, is lined with gutta-percha; and it is 45 inches long, 22 inches wide, and 32 inches deep. In proceeding to prepare for work, the trough, whether of the size above-mentioned or otherwise, is filled with water in combination with hydrochlorate of ammonia (sal-ammoniac), in the proportion of 1,000 pounds by weight of water, to 100 pounds of hydrochlorate of ammonia. A plate of sheet iron, nearly as long, and as deep as the trough, is attached to the positive pole of the battery, and immersed in the solution. Another plate of sheet iron, about half the size of the other, is attached to the negative pole of the battery, and immersed in the solution; and when the solution has arrived at the proper condition (which will require several days), the plate of iron attached to the negative pole is removed, and the printing-surface to be coated is attached to such pole, and then immersed in the bath till the required coating of iron is obtained thereto. If, on immersing the copper plate in the solution, it be not immediately coated with a bright coating of iron all over, the bath is not in a proper condition, and the copper plate is to be removed, and the iron plate attached, and returned into the solution. The time occupied in obtaining a proper coating of iron to a printing-surface, varies from a variety of causes; but a workman, after some experience, and by careful attention,

will readily know when to remove the plate from the solution ; and it is desirable to state, that a copper plate should not be allowed to remain in the bath, and attached to the negative pole of the battery, after the bright coating of iron begins to show a blackish appearance at the edges. Immediately on taking a copper plate from the bath, great care is to be observed in washing off the solution from all parts ; and this, I believe, may be most conveniently done by causing jets of water forcibly to strike against all parts of the surface. The plate is then dried and washed with spirits of turpentine, when it is ready for being printed from in the ordinary manner.

"If an engraved copper plate be prepared by this process, instead of a comparatively limited number of impressions being obtained, and the plate wearing out gradually, a very large number can be printed off without any sign of wear in the plate, the iron coating protecting it effectually : the operation of coating can be repeated as many times as required ; so that an almost unlimited number of impressions can be obtained from one plate, and that a copper one.

"This process will be found extremely valuable for electrotype plates, and also for photo-galvanic plates, since they can be so protected as to acquire the durability of steel ; and more so, for a steel plate will require repairing from time to time ; these will not, but simply re-coating whenever it is found necessary : by these means one electro-copper plate has yielded more than 12,000 impressions, and was found quite unimpaired when examined minutely.

"It is easy to appreciate the importance of this invention, as applied to artistic or line engraving more especially ; for a copper plate being once engraved, if submitted to the acierage process, will become a lasting property, not liable to deterioration by printing, and the public may expect to be supplied with the very best impressions at a more moderate charge ; whilst to the numerous branches of commercial engraving, for the ceramic manufactures and others, as well as to the vast number of old engraved copper plates existing in this country, this process is likely to confer an immense additional value.

"I need not say that copper is by no means the only metal to which the process is applicable, for the same principle will be found to answer in the case of other soft metals used for printing purposes ; and I shall only add, in conclusion, that although the principle of electrotyping has been applied, up to the present date, in a variety of ways since it was organised by Thomas Spencer, in 1837, this is, I believe, the first time that an attempt has been successfully made to prepare an engraved copper plate with harder metal, with the view of increasing its printing capabilities ; and I feel happy to have been the first to introduce so valuable a discovery into this, my adopted country."

To the value of M. Joubert's invention we can bear a daily experience of some years. It is now much employed by many of the largest printing firms in this country, and is one of the very few successful applications of science that has stood so long the test of time with increasing rather than decreased reputation.

The process generally adopted, at the present time, is a modification of that of M. Joubert's acierage ; but the general method of procedure is that which has been described in the inventor's own words. The method is not only exceedingly ingenious, and of great value, but, indirectly, tends to promote a taste for art ; because, as the saving of re-engraving plates is very large, the cost of producing copies on paper is, consequently, much reduced.

Silver or Plating Solutions.—Perhaps the most extended application of any process of metallurgy, is that of depositing silver on the surface of metals of greatly inferior value, and generally, but fancifully, termed "base," by which they are rendered not only equal in appearance to articles entirely made of silver, or Sheffield plate, but, in certain respects, superior ; because the electro-deposit is of pure silver, whilst all "plate goods," technically so termed, are made of silver alloyed with copper.

But the word "base" has a proper signification in certain cases. The proper basis of an electro-silver surface should be some hard, tenacious, and firm metal, capable of withstanding as much mechanical violence, at least, as a solid silver article would sustain without serious injury ; and such a basis is readily found in copper, nickel-silver, German silver, brass, and many other alloys. Unfortunately, however, science is now greatly prostituted in a variety of ways ; and in none more so than in the use of cheap soft metal alloys, that too frequently are used as the solid superstructure of tea and coffee-pots, sugar-basins, &c., &c. Such material can be coated with silver, by electro-deposition, just as well as copper, or the alloys above-mentioned ; but the articles, whilst looking just as well, are absolutely useless for domestic and other purposes. They have little or no power of resisting accidental blows, or the other incidents of life that militate against the stability of an article. In the language of the trade, they are called "duffers"—an emphatic, although not very refined phrase, but still describing the character of the article. Large quantities of these are got up for mock-auction sales, at which inexperienced purchasers are completely taken in ; and, unfortunately, the law cannot be employed to the criminal prosecution of the vendors ; for it has been held, by the judges, that the sale of such articles is one in which *caveat emptor* is necessary, and that the sin of the seller simply rests in "over-exaggeration of the value of the article." It seems somewhat anomalous, that if the buyer of such articles were to offer *them in pledge*, he would most likely submit himself to a punishment of some months' imprisonment. But British law always has had its anomalies ; and hence the dupe has no remedy but civil action against men who have neither money nor character to part with.

We have already pointed out, at p. 289, *ante*, the difficulties that first presented themselves in obtaining a solution that would deposit a good

reguline silver ; and have stated that such were eventually overcome by employing a solution of cyanide of silver dissolved in cyanide of potassium, by means of which a double cyanide—that is, one of the two metals—can be made. Practically, this is the only "silver solution" employed in electro-plating. It is one easily made, readily worked, and fulfils all the conditions named at p. 289, for making a good depositing liquid.

The materials usually employed to make the cyanide solution for electro-plating, are the nitrate of silver and cyanide of potassium. In respect to the first, sufficient has been said at p. 290, *ante*. If, however, the operator prefers to make his own nitrate of silver, the best plan is that of purchasing *pure* silver from the refiners, and dissolving it, with the aid of heat, in dilute nitric acid, that should be quite free from hydrochloric acid. To test the freedom of the acid from the latter, directions have already been given at p. 272, *ante;* and it may, therefore, be here only added, that if any hydrochloric acid be present, an equivalent portion of silver will be thrown down as chloride ; that is, for every 36·5 grains of *real* hydrochloric acid present, 108 grains of silver will be precipitated as 144·5 grains of chloride of silver. Should this occur, the chloride of silver must be filtered from the nitrate solution ; and, at a subsequent page, directions will be given for its reduction again to the metallic state.

It has been stated that *pure* silver must be employed to make the nitrate. Standard silver contains a portion of copper as an alloy, which is added to pure silver, to give it sufficient hardness to resist wear and tear, either as coin or plate. Hence it is unfit both for making the nitrate, and also for being used as an anode. The silver for solution may be the pure grain ; but, as an anode, it must be first rolled into the bar or foil form, because extended surface is required to fit it for acting as an anode.

In some cases it may happen that the electroplater can economically prepare his own pure silver ; because it frequently happens that such take old plated goods in exchange, from which the standard silver can be removed ; and also old silver, of the standard kind, is occasionally taken in exchange for other goods. In such cases pure silver may be obtained by following either of the following plans.

In respect to "stripping" Sheffield plate, worn away by constant use, and off which it is desired to get the silver, the succeeding process may be employed :—"Add a little nitrate of potash, or common nitre, to a quantity of strong sulphuric acid [by which nitric acid in solution and a solvent of silver is obtained], and apply heat until it is all dissolved. If the action become slow, apply more heat, or add more saltpetre. The copper will not be much acted on if the articles are not allowed to remain too long [in this solution]. A number of them are generally done together, and are afterwards washed, and prepared in the usual manner [to be afterwards described] for receiving a deposit [of silver]. The silver may be recovered from the liquid [which, by the preceding process, contains the nitrates of copper and silver] in the form of chloride of silver, by diluting it with much water, and then adding a solution of common salt so long as a precipitate is produced." The precipitate should then be received on a filter, and be well washed with water, to remove all traces of copper, &c., in solution. After such careful washing it should be dried by placing the filtering-paper on which it has been collected in an oven, or a water-bath. It is then to be mixed with carbonate of potash, the mixture being afterwards put into a crucible, and, after fusion, metallic silver, perfectly pure, will be obtained.

In any case, alloys of silver, soluble in nitric acid, may be similarly treated to obtain pure silver. Thus, if the ordinary coin be dissolved in nitric acid, and any soluble chloride be added to it, a precipitate of chloride of silver is obtained. For the sake of cheapness, the chloride, after washing and drying, may be mixed with chalk. For this purpose, 100 parts, by weight, of the chloride of silver may be mixed in a mortar, with about seventy parts of pure chalk ; and to this mixture should be added five parts, by weight, of powdered wood charcoal. The mixture so effected is to be put into an earthen crucible, and exposed to a white heat. By this the silver is reduced, and will form a mass, owing to its greater specific gravity, at the bottom of the crucible.

Another method, partially by the "wet way," may also be employed; and its success is chiefly due to electro-chemical action. It is pursued as follows :—Chloride of silver, produced by any of the preceding methods, and in fine powder, is suspended by agitation in water acidulated with a little hydrochloric acid, and fragments of zinc are to be immersed. The chloride of silver, by this treatment, is rapidly decomposed, chloride of zinc being formed, and remaining in solution, and pure silver, in a finely-divided condition, being thrown down. Practically, in order to assure the complete absence of zinc, it is as well to fuse the pulverulent silver resulting from this operation with a little commercial borax. Instead of zinc, iron may be employed ; and this modification of the process is important, as constituting the process by which silver is occasionally extracted from its ore in America and Saxony. The silver ore (a sulphide) being reduced to powder, is intimately mixed with common salt (chloride of sodium), and roasted in a furnace, by which treatment chloride of silver is generated ; and the latter being intimately mixed with scraps of metallic iron and mercury, and well incorporated, an amalgam, or compound of silver, with mercury, results. The latter is freed from a portion of its mercury by straining through a linen cloth ; and, finally, the whole of the mercury is separated by distillation.

Other methods of obtaining pure silver from its alloy with copper, as in coin and plate, are as follows :—(1) The alloyed silver having been dissolved in nitric acid, the solution is evaporated to dryness, and the dry mass fused. By

this treatment the nitrate of copper is decomposed into the elements of nitric acid, which, being volatile, are evolved, and oxide of copper, which remains diffused through the liquefied nitrate of silver, which is coloured brown in consequence. From time to time a little of the fused product is removed on the extremity of a glass rod, dissolved with water, and tested by ammonia; so long as any nitrate of copper remains undecomposed, the solution turns blue when ammonia is added; but as soon as the decomposition of nitrate of copper is complete, this change does not take place. The fused mass being now removed from the fire, allowed to grow cold, dissolved in water, and the solution filtered, yields a solution of pure nitrate of silver, which is to be evaporated as before until crystals are produced. (2) A solution of mixed nitrate of silver and nitrate of copper having been made by dissolving standard silver in nitric acid, one-fifth part of it is to be precipitated by cold potash solution added in excess. By this treatment all the oxide of silver and oxide of copper are thrown down. The mixed oxides having been well washed for the purpose of removing potash, are to be added to the remaining four-fifths of the solution, and boiled, by which treatment the whole of the oxide of copper is thrown down, and a solution of pure nitrate of silver remains, which may be converted into chloride by the addition of common salt, and treated as before for the reduction of metallic silver.

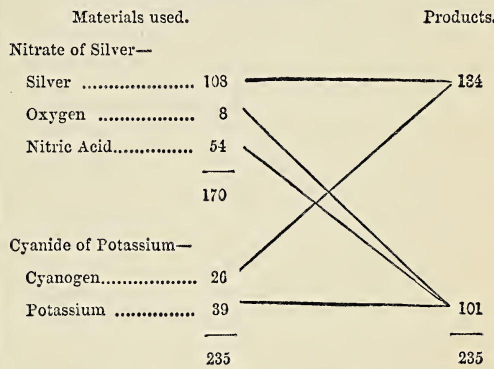
By any of the preceding methods, old plate, whether Sheffield or of standard silver, may be converted into pure silver, so far as that metal is a constituent of such articles. It is frequently a question of economy to use such methods by the electro-metallurgist. But if such occasions do not arise, we fancy that the purchase of pure nitrate of silver (wholesale) will, for the small operator, be, in general, the cheapest and most economical plan.

Having thus obtained the nitrate of silver solution, the next point is its conversion into the cyanide. Formerly, the method was, to add lime, or any alkali or alkaline earth, to a solution of the nitrate of silver, and thus to obtain the oxide of the latter metal. This is a somewhat troublesome process, because the decomposition goes on slowly, the precipitated oxide of silver being bulky; and, if lime-water be used, a large amount of liquid must be employed, on account of the trifling solubility of lime in water. When the oxide of silver is so precipitated, it must be well washed, to free it from nitrate of lime. This is best done by filtering the liquid and precipitate by pouring both into a funnel holding a filter of bibulous paper. The liquid will, of course, speedily pass through the paper; and, on the solid residue left on the filter, distilled water is to be poured for some time, so as to free it from all soluble matter. The oxide so formed is to be dissolved in cyanide of potassium, so as to form a double cyanide of silver and potassium, which constitutes the ordinary plating solution employed in electro-metallurgy. Its nature, &c., will be better understood as we proceed in describing other processes affording the same results.

If cyanide of potassium be added to nitrate of silver, each in atomic proportions, a cyanide of silver, which is insoluble, and nitrate of potash, or nitre, which is held in solution, are the results.

By referring to p. 270, *ante*, under the heads of *Potassium*, *Cyanide*, and *Silver Nitrate*, it will be perceived that, if both substances be pure, 65 grains of cyanide of potassium should exactly neutralise 170 grains of nitrate of silver; and, consequently, the following changes, as represented in the diagram, take place.

Decomposition of Nitrate of Silver by Cyanide of Potassium.



Consequently, every 170 grains of nitrate of silver should yield, with cyanide of potassium, both being absolutely pure, 134 grains of cyanide of silver.

Theoretically, therefore, to prepare cyanide of silver by the addition to it, in solution, of a solution of cyanide of potassium, 65 parts of the latter should precipitate 170 of the former, to produce 134 parts of cyanide of silver. But, as we shall subsequently notice, the cyanide of potassium met with in commerce is always more or less impure. Consequently, allowance should be made for this; and, therefore, at least one-third of the weight of the nitrate of silver will be required of ordinary cyanide of potassium to completely precipitate a given weight of nitrate of silver.

Practically, the following method has been recommended for making the nitrate of silver, and the cyanide therefrom:—

"Take four parts [by weight] of grain silver; add it, in small portions at a time, to a warm mixture of about five parts of strong commercial nitric acid [specific gravity 1·5], and one of water, contained either in a glass or stoneware vessel. Gas [various compounds of nitrogen and oxygen] will be evolved from the surface of the silver [or the liquid], and brown fumes of 'nitrous acid' [or, more correctly, of oxidated binoxide of nitrogen] will arise from the mixture. * * * * The action should be maintained moderate and uniform; and if it should become too strong, a little cold [distilled] water should

be added, and the mixture kept cooler. When the whole of the metal is dissolved, apply heat, and evaporate the solution to dryness, which operation will drive off any excess of acid present. The resulting salt is nitrate of silver, which may then be dissolved in water, in the proportion of about half a gallon to each ounce of silver used. At the same time, a solution should be made of from 3 to $3\frac{1}{4}$ parts (according to its quality) of cyanide of potassium in 30 or 40 parts of water, which is to be *gradually* added to the solution of nitrate of silver as long as it produces a precipitate. If too much be added, it will cause some of the precipitate [the cyanide of silver] to be re-dissolved, and be wasted. In such a case the liquid should be stirred, and allowed afterwards to settle till quite clear; and a small quantity of a solution of nitrate of silver should be added so long as the latter produces a white cloud. By conducting the operation in a glass vessel, adding the liquid towards the latter period in small quantities at a time, and at intervals of a few minutes each, with gentle stirring immediately upon each addition, carefully observing when it ceases to produce a precipitate, the point of neutralisation may be very accurately determined. The liquid must now be allowed to remain undisturbed until quite clear: the clear portion is then to be poured steadily away from the precipitated cyanide of silver." The latter should then be collected on a filter, and abundantly washed with water, to remove all trace of nitrate of potash by the process, as indicated by the last preceding diagram.

By such means the cyanide of silver is obtained, and it only requires that it should be rendered soluble to make a silver depositing liquid, which is done thus:—"Dissolve from three to four parts [according to quality] of cyanide of potassium in twenty parts of water, adding it, in portions at a time, to the wet cyanide of silver until the whole of the latter is dissolved. Then add about three parts more of cyanide of potassium to form *free* cyanide [see *ante*, p. 289], and sufficient water to reduce the whole to the proportion of about one ounce of silver to one imperial gallon of the solution. Finally, when all the free cyanide is dissolved, filter the solution through the best white blotting or other *unsized* paper."

The method of making the silver solution by the battery process has been already named at p. 290, *ante*. On this Mr. Gore observes—"This process has its advantages and disadvantages. It is very convenient in making a small quantity of liquid, because it enables the operator to do so quickly, to avoid the trouble of making the nitrate of silver solution, of precipitation, of washing, and of the attendant risk of loss of materials. But it has the disadvantage of converting a large proportion of the cyanide of potassium into caustic potash, by taking its cyanogen to form cyanide of silver, and setting the potassium free, which immediately combines with the oxygen of the water, forming caustic potash, which dissolves in the liquid. The hydrogen of the water is evolved at the cathode, and the dissolved potash gradually becomes converted into carbonate of potash by absorption of carbonic acid from the atmosphere. Neither caustic potash nor carbonate of potash are so injurious in the liquid as chloride of potassium; still they diminish the action of the liquid upon the dissolving plate, render it a worse conductor, reduce its solvent power for cyanide of silver, and make its particles less mobile."

The battery process, of course, requires a cyanide solution, a large anode of pure silver, and a small cathode, which may be of brightly-polished copper. The deposition of a good coating of silver on the latter will show the proper effect in thus making the silver solution.

It has already been pointed out, that all plating and gilding solutions are only properly effective when they contain *free cyanide*, just as free acid is required in the sulphate of copper solution. The sulphuric acid added for such purposes to the latter, undergoes no change if the solution be in use for years. Not so, however, in regard to the cyanide solutions: gradually these become deteriorated by the action of the atmosphere, and from other causes. In respect to this, and other matters relating to the management of silver solutions, the following remarks, quoted from the authority just named, will be of great practical value:—

"Many electro-platers use a cyanide solution containing about half an ounce of silver to the gallon, and add a very large proportion of free cyanide of potassium, to make it conduct freely. Such a solution has the advantage of being comparatively inexpensive in its first formation, quick in working, and yields metal of an average character; but it is rather difficult to manage in hot weather, and dissolves the anode very rapidly, on account of the large proportion of free cyanide. In practice, the amount of silver to the gallon varies from half an ounce to about four ounces; but ordinary solutions contain from one to two ounces. The amount of *free* cyanide of potassium also varies from about half the weight of silver dissolved in the liquid to five or ten times that quantity. A very good proportion is about three-fourths of the weight of dissolved silver. But there is no rule generally recognised in the trade upon this point, some manufacturers using a very large, and others a very small proportion.

"A good plating liquid should contain one equivalent, or sixty-five parts of pure cyanide of potassium, and one equivalent, or 134 parts of cyanide of silver [see diagram at p. 297, *ante*], besides *free* cyanide, and sufficient water to form a thin liquid. It is necessary to have free cyanide, because, in working the solution, insoluble cyanide of silver is formed, and requires free cyanide of potassium to combine with it, and form the soluble double cyanide. At the same time cyanogen and cyanide of potassium are set free at the cathode, or receiving surface, by the deposition of the silver; and as it requires some time for those substances to mix with the liquid, and reach the dissolving plate [or anode], *free* cyanide must be provided. The necessity of having sufficient water to form a

thin liquid arises from the double cyanide, formed at the dissolving plate, being specifically heavier than the liquid, having a tendency to sink to the bottom; whilst the cyanogen and cyanide of potassium set free at the surface of the articles, being specifically lighter than the solution, tend to rise to its surface. At the same time, each of them mixes, more or less, with the surrounding liquid by capillary attraction or adhesion; and the more dilute the liquid is, the more mobile are its particles, and the more rapidly does this mixture take place. This explains why strong silver solutions require more frequent stirring than weak ones to keep them uniform. In some manufactures, where they have steam-power at command, the articles are kept in constant motion by machinery swinging them gently to and fro; but, in ordinary electro-plating establishments, the silver solutions are stirred every evening.

"If a solution contain but little water, and a large supply of free cyanide, and, from any cause, the electric current become suddenly weak towards the evening, the silver deposited upon the articles will be re-dissolved, in consequence of the liquid about the dissolving sheets having, by the day's work, become saturated with silver, and that about the articles becomes full of free cyanide. The two electrodes—that is, the dissolving plates and the articles—then form a kind of voltaic battery of one metal in two liquids, which develops a current of electricity in an opposite direction to the original one, and thus re-dissolves the deposited silver."

The same authority also remarks on the proportion of free cyanide—"It is necessary to add a little cyanide of potassium occasionally to every cyanide of silver-plating liquid, probably because the solutions absorb carbonic acid from the atmosphere, which converts some of the cyanide of potassium into carbonate of potash, and sets hydrocyanic acid vapour free. A further portion of the salt may also be decomposed by other means, with formation and escape of ammonia. The necessity of adding a little fresh cyanide of potassium is indicated when the dissolving liquid begins to change from its ordinary pure white appearance to a dull yellowish-gray colour. It is best added in the evening, after plating [when the day's work is done, and the solution no longer needed], about half-an-hour before stirring the solution.

"If the latter be too strong—that is, if it contain insufficient water, but has silver and cyanide of potassium in their proper relative proportions—it conducts freely, deposits rapidly, and gives a rich deposit of a fine silky lustre. But it is more difficult to manage than a weaker liquid, especially in hot weather, because, from the less mobility of its particles, it is very apt to settle, by working, into strata of different densities—its upper part becoming exhausted of silver, and full of free cyanide, and its lower part becoming nearly saturated with that metal, and destitute of free cyanide. The consequence of this is, that the upper parts of the dissolving plates waste rapidly, whilst the upper parts of the articles [to be plated] receive either very little deposit, or one of a bad quality, being gray, brown, or yellowish—sometimes of a lilac hue, and generally in dull, streaky, vertical lines. All these evils may be mitigated by stirring the solution well every night, after having finished plating; or may be entirely prevented by diluting the liquid with water to a proper extent, stirring it every evening, and working it uniformly. All silvering and other depositing liquids exhibit this tendency to settle into strata in working, especially if worked rapidly; but the most dilute show it in the least degree.

"If the solution be deficient of water, and contain a great excess of free cyanide, the foregoing evils are all greatly aggravated. In hot weather it becomes very unmanageable; and the vapours of ammonia and hydrocyanic acid arising from it are quite overpowering. In this case, the best way to improve it is to add cyanide of silver and water, in sufficient quantities to make it of a good composition; keep it in a cool place, stir it daily, and work it constantly, in a uniform and careful manner. New solutions, or old ones which have been injured, often improve by daily stirring, with regular and judicious working. An excess of cyanide of potassium is indicated when the dissolving plates are very strongly acted on, and the deposit is, at the same time, either very sparing, or of a bad colour.

"If the solution be too weak—that is, if it contain too much water—it conducts sparingly, deposits slowly, and the deposit has a dead-white appearance. This may be easily remedied by adding cyanide of silver and cyanide of potassium to it, in proper proportions [see *ante*, p. 298], and working it uniformly a few days, with daily stirring."

By the preceding remarks, the practical man will be put into possession of most of the causes that favour or oppose success in electro-plating solutions; we may, however, add some observations on the method of analysing, and otherwise testing the strength of a plating solution.

A simple, but not always certain, guide is specific gravity. Of course, a solution of cyanide of potassium will have a greater specific gravity than distilled water; and one of cyanide of silver and potassium will be heavier than one of cyanide of potassium; and if these two salts were alone present in a silvering solution, the hydrometer would afford excellent indication of the strength of a silvering solution. So soon, however, as free potass and the carbonate commence to be formed, as previously described to occur, then the indications of the hydrometer cease to be of value; because those substances, whilst not adding in the slightest degree to the quality of the solution, and, in fact, deteriorating it, still would show a factitious strength, just as if the latter were caused by the silver solution. But in first making the silver solution, and in producing others of equal strength, the hydrometer may be employed, because no extraneous matter will at first be (or should not be) present in the newly-made solution.

Any form of hydrometer may be employed, having on its stem specific gravities marked from 1·000, as the standard of water, and upwards, or according to the systems of Twaddell and Beaumé. In all cases uniformity of temperature must be insured; because, if two solutions be tested at temperatures different from each other, although, if of *one* temperature, their specific gravities might agree, the difference of temperature will cause a difference in the apparent specific gravity.

The hydrometer is easily used. It simply requires placing in the liquid, into which it will sink until the mark on the scale inside its stem will indicate the strength. The following tables show the equivalent values existing between the real gravity, compared with distilled water as a standard, and the scales of Twaddell and Beaumé.

Equivalent of Degrees of Twaddell to Ordinary Specific Gravity.

Specific Gravity. Water = 1·000.	Twaddell Degrees.
1·000	0
1·050	10
1·100	20
1·150	30
1·200	40
1·250	50
1·300	60
1·350	70
1·400	80
1·450	90
1·500	100
1·550	110
1·600	120
1·650	130
1·700	140
1·750	150
1·800	160
1·850	170
1·900	180
1·950	190
2·000	200

Beaumé's corresponding scale is as follows:—

Specific Gravity.	Beaumé's Degrees.
1·000	0
1·036	5
1·075	10
1·116	15
1·161	20
1·210	25
1·264	30
1·321	35
1·385	40
1·454	45
1·532	50
1·618	55
1·714	60
1·823	65
1·946	70

The cost of any of these kind of hydrometers is very trifling; and the specific gravity may be either taken in the depositing-trough, or in a separate tall glass cylinder. For reasons already assigned at p. 299, *ante*—that is, uniformity of strength—the liquid, if tested in the depositing-vat, should be stirred before the hydrometer is used.

The most exact method is, of course, that of chemical analysis; and this may be performed directly, or by the volumetric method, as follows:—

1. *Direct Analysis for Testing the Amount of Silver present.*—Take a fluid ounce of the solution, and add dilute sulphuric acid to it as long as it produces a precipitate. By this means the potassium becomes converted into potass, which unites with the acid to form a solution of sulphate of potass, whilst cyanide of silver is precipitated. This should be collected and filtered, being well washed with distilled water, the filter having been first carefully weighed. The precipitate is then to be dried at a gentle heat, and weighed. Deducting the weight of the filter, that of the precipitate will, by calculation, give the weight of silver present thus:—Referring to p. 270, *ante* (*Silver, Cyanide of*), it will be seen that cyanide of silver is composed of—

Silver	108
Cyanogen	26
	134

Hence every 134 grains of the cyanide precipitated as above, indicate 108 grains of silver present. And for any other weight of precipitate produced, a rule-of-three sum may be made. Thus, supposing 67 grains of precipitate are given, the following proportion is to be made:—

As the equivalent (134) of cyanide of silver
Is to the weight (67 grains) obtained by precipitation,
So is the equivalent (108) of silver
To the amount of silver in the 67 grains of cyanide, x.

$$134 : 67 : : 108 : x.$$

$$\left.\begin{array}{l}\text{Here } x\text{, the weight of}\\ \text{silver in the pre-}\\ \text{cipitate . . . .}\end{array}\right\} = \frac{67 \times 108}{134} = 54$$

Hence the 67 grains of obtained precipitate contain 54 grains of silver.

2. *To Test the Amount of Free Cyanide in a Solution.*—Take a fluid ounce as before, and add to it a solution of pure nitrate of silver in distilled water, so long as any precipitate continues to be dissolved, keeping the liquid constantly stirred. When the free cyanide is completely neutralised, the precipitate will not be re-dissolved; but the operation must stop exactly at that point. If now a known weight of nitrate of silver has been dissolved in water, and put into a glass vessel divided into one hundred parts, it is evident that the number of these parts required to neutralise the free cyanide will indicate the weight of silver required, and, consequently, of the *free* cyanide present in the solution. Referring to p. 270, *ante*, it will be seen that the equivalent of nitrate of silver is 170, and that of cyanide of potassium 65. But two equivalents

of the latter must be present, one to precipitate the silver, and another to re-dissolve it; hence, for every 170 grains of nitrate of silver used, 130 grains of free cyanide must be present. These proportions are near enough in practice, as 4 is to 3; or, in other words, for every 4 grains of nitrate of silver that are required to neutralise the free cyanide in a solution, it may be estimated that 3 grains of the latter are present.

3. *The Volumetric Method.*—This proceeds from an expansion of the last method, or rather a double application of it. The plan has the advantage of requiring no weighing, drying, &c., and is carried on as follows:—

It is evident, from the preceding statements, and from the diagram already given at p. 297, *ante*, that 170 grains of nitrate of silver will exactly neutralise 65 grains of cyanide of potassium, producing 134 grains of cyanide of silver, and 101 grains of nitrate of potass. It hence results that, if two separate solutions be made of the two salts in equal *measures* of water—as, for example, if 170 grains of nitrate of silver be dissolved in 100 measures of water, and 65 grains of cyanide of potassium be also dissolved in 100 measures of water—the two solutions would exactly neutralise each other. Again, if the solution of silver contained only half 170 grains, it would only take one-half of the 100 measures of cyanide to precipitate it. Therefore, the number of measures required of one solution to neutralise exactly the other, becomes at once an indication of the strength of the latter.

The practical application for ascertaining, say the free cyanide in a solution for silvering, may be effected thus:—Take a definite quantity, in bulk, of the solution, and dilute it with water if necessary—that is, if very strong—so as to fill a measure of 100 parts. To this add the standard solution of nitrate of silver, made in equal 100 measures, as before directed. Keep the mixture well stirred, by doing which the precipitate at first formed will be re-dissolved. Add the nitrate gradually, and, *at the moment (which must be particularly noticed)* that the precipitate ceases to be re-dissolved, all the free cyanogen will have been neutralised. At this point, one equivalent of silver in the solution has combined with two of cyanogen. Consequently, if the quantity of silver solution that has been used be noticed, the amount of cyanogen present may be calculated, and also, as a matter of course, the amount of free cyanide of potassium present.

This latter plan is of great practical value; and, with ordinary care, perfectly succeeds.

According to Mr. Griffin's method of volumetric analysis, 170 grains of nitrate of silver are to be dissolved in a *decigallon* of water; that is, 1 pound, or 7,000 grains of that liquid. A *septem*, or one-thousandth part, by measure, of this will contain 0·17 grains of nitrate of silver; and, in using such a solution for the estimation of free cyanide, as just described, each septem of the nitrate required indicates 0·052 grains of cyanogen, or 0·130 grains of cyanide of potassium.

By these plans, it will be seen that an immense amount of trouble may be saved, and very accurate results obtained; reasons for adopting which at once commend themselves to the sound sense of the practical man.

So far we have dealt with the ordinary silvering solutions, and have not, as yet, named a modification that is of considerable practical importance in the art. We refer to "bright solutions," by which the labour of burnishing electro-plated articles is lessened. According to Mr. Gore, the discovery was made as follows:—Some operators at the electro-plating works of Elkington and Mason, at Birmingham, were engaged in experiments on moulds containing bisulphide of carbon. Whilst these moulds were being coated with silver in the depositing-vats, very peculiar appearances upon the various articles receiving a deposit in the vats were noticed, some of them having very bright patches upon them, like burnished metal. From the known presence of bisulphide of carbon, experiments were tried of adding that liquid to a quantity of silvering solution, which ultimately resulted in success; and a patent was taken out by Messrs. Lyons and Milward, dated March 23rd, 1847, in which they gave the following instructions for forming a bright solution:—

"Add to the usual solution of silver, in cyanide of potassium, bisulphide of carbon, terchloride, or other chloride of carbon, sesquichloride of sulphur, or hyposulphite of either potash or soda. The bisulphide of carbon may be used alone, or dissolved in [mixed with] sulphuric ether; or it may be used in conjunction with any of the other substances mentioned above; but the patentees prefer using it as follows:—Six ounces of bisulphide of carbon are put into a stoppered bottle, and one gallon of the usual plating liquid is added to it. The mixture is then to be shaken, and set aside for twenty-four hours. Two ounces of the resulting solution are then added to every twenty gallons of the ordinary plating solution in the vat, and the whole stirred together. This proportion must be added every day [to the bulk of the working solution], on account of loss by evaporation; but when the mixture has been made several days, less than this proportion may be used at a time. When hydrocarbons are used instead of the bisulphide, a much larger quantity must be added. This proportion gives a bright deposit; but by adding a larger quantity, a dead surface may be obtained, very different to the ordinary dead surface." Many other highly carbonous substances or liquids have been employed for the same purpose, such as a solution of iodine and gutta-percha in chloroform, sulphur, collodion, &c. The management of this bright solution is somewhat difficult. "If it be not worked constantly, and in a uniform manner, it will lose its power of yielding bright metal. If any of the articles which are being plated in it are disturbed, or removed from the liquid, and replaced, that one will not then receive a bright deposit; and the disturbance of the liquid by

removing it, will oftentimes cause all the neighbouring articles to lose their brightness. If too much brightening liquid be added, the solution will be considerably injured; indeed, many silver solutions have been irretrievably damaged in this way."

A bright solution requires a battery current of large quantity and low intensity to work it, and the dissolving plates in it are generally of a darker colour than those in the ordinary silvering liquid. The silver deposited from it is much harder than that deposited from the ordinary plating solution, and has very much the appearance of fused metal. The light appearance commences at the upper part of the articles, and travels downwards. It soon after commences at their lower extremities, and travels upwards until the bright portions meet each other. If there are very small holes in the surface of the articles, dull streaks appear above the holes.

In 1866, we were engaged in a variety of experiments on the deposition of metals; but especially nickel and silver, separately, and combined as a quasi-alloy. By some carelessness on our part, a mixture of the cyanides of these metals was poured into a wooden trough that had been lined with a mixture of tallow and pitch. Of course, very speedily the potass, set free by atmospheric decomposition of the free cyanide of potassium, acted on the lining, and dissolved it, forming an opaque, dark-brown solution, filled with pitch and the creosote the latter contained. Not wishing, however, to waste nearly a gallon of the solution, we tried to deposit the mixed metals, and at once obtained a bright polished surface, which, however, by long action, deteriorated gradually, and became very "patchy." On one occasion, a bright band, across a copper plate, was formed, the edges of which were perfectly defined, as if every other part of the plate had been stripped off. This resulted from immersing the plate in the wrong way—horizontally instead of perpendicularly. On reversing it, a broad band, three or four inches wide, was immediately formed of bright metallic deposit, of great polish and tenacity, whilst the rest of the plate was entirely unaffected, affording an anomalous action that we have never yet been able to account for, simply, perhaps, because, in the excitement of experimental research, we forgot some cause or circumstance that must have contributed to the result, which, by the way, we never succeeded subsequently in attaining.

It is somewhat difficult to account conclusively on any one cause productive of the "bright" surfaces resulting as above. The *result* is evidently due to a molecular arrangement of the particles of the metal deposited on the cathode. Now *polish*, or brightness of surface, is evidently due to a lessening of the distance between the contiguous parts of a surface. For example, an unpolished surface is one that presents an irregular surface; but if the projecting portions be rubbed down, or, in any other way, the irregular distribution of the particles of the surface be overcome, polish is the result. Glass, for example, however uneven on its surface, as effected by cutting, &c., may be polished by the successive application, by friction, of various polishing powders, the office of which is to render the surface uniform in texture. But this is simply a rough mechanical mode of arriving at such a result, and can have no relation to the effect of a "bright solution," used in metallurgy, further than to show the effect of a re-arrangement of particles in reference to the reflection of light from surfaces.

We have always been tempted to view the effect of a "brightening" solution to that produced in the beautiful method of silvering the internal surface of a glass globe. If such be filled with a solution of nitrate of silver, to which a few drops of some essential oils have been added, and the globe be exposed to light, the silver will become deoxidised, and precipitated in the metallic condition on the internal surface of the globe, affording a fine reflecting surface. It is by no means impossible that electricity may, in the "brightening" solution, take the place of light in producing the analogous effect of affording a polished or bright silver cathode surface. We simply throw out the idea as a suggestion, without attaching any weight to it. One thing is certain, that sulphide of carbon, and the other carbonous or other hydro-carbonous substances that have been used for such purposes, are the analogues of the essential oils employed in the silvering of glass globes; and it does not seem contrary to strict philosophy, if we venture still further to suppose, that electricity, in the bright electro-deposition, may be viewed as the analogical representative or substitute, in the latter operation, of the light in the preceding one.

We have devoted much space to the consideration of silvering liquids, because of their great commercial importance; and shall now turn to a description of the best methods of making cyanide of potassium, having described every other chemical required in the process, and presuming that some of our readers may be glad of recipes, and the rationale of the most approved methods.

Cyanogen, as already noticed, is a compound of one equivalent of nitrogen and two of carbon, expressed, according to the hydrogen scale, as—

Nitrogen . . .	14
2 of Carbon = 2 × 6 . . .	12
	26

It was discovered by Gay-Lussac, the celebrated French chemist; and in respect to its commercial, medicinal, and other aspects, may rank amongst the most important of all chemical compounds. Its peculiar characteristic is, that although evidently a compound body, it may be considered as the analogue of oxygen, chlorine, iodine, bromine, fluorine, sulphur, carbon, phosphorus, selenium, &c.; for just as these form, with metallic bases, respectively, oxides, chlorides, iodides, bromides, fluorides, sulphides, carbides, phosphides, &c., so cyanogen is capable of producing their analogues, *cyanides;* hence,

whilst having none of the attributes, *per se*, of the elementary bodies previously mentioned, its compounds have no distinctive difference in certain respects. This is a peculiar anomaly in the science of chemistry, and shows that, however advanced our knowledge may seem to be, we have not only much to learn, but, at some future period, may find that certain chemical theories will not only have to be modified, but they may be completely overturned. This, however, is a matter that we cannot stop here to discuss; for it would lead us into a maze of fact and argument that would result in an entire oblivion of our present purpose.

Hydrocyanic or prussic acid is an important product of cyanogen; and here we find a still further analogy between it and chlorine, &c. Thus whilst we have hydro-*chloric*, hydr-*iodic*, hydro-*bromic*, and hydro-*sulphuric* acids, so have we the hydro-*cyanic*, in all cases hydrogen playing an important part, even, apparently, as an acidifying agent, with what we can hardly otherwise term *bases*, although such an idea entirely controverts previously-received views of the nature of acids.

It has yet to be discovered how we can *directly* unite carbon with nitrogen to produce cyanogen; but, indirectly, the process is easy enough. If required free, for the purpose of experimental investigation of its nature, the usual method is, to heat cyanide of mercury, the preparation of which has been already described at a previous page. The solution obtained, as there directed, is to be evaporated, when crystals of the cyanide of mercury will be obtained. These are to be heated in a bent-glass tube, or a retort, by means of a spirit-lamp, as represented in the following engraving. The gas that is given off

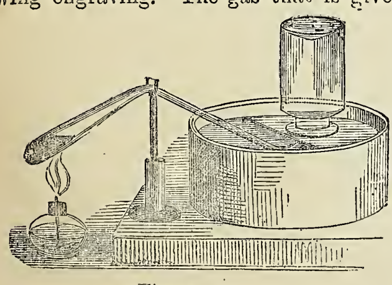


Fig. 177.

may be received over water, in the ordinary water or mercury pneumatic trough. The heat will volatilise two products—namely, mercury in the metallic state, and cyanogen. The latter will be recognised as a gas, free from colour, having an odour like peach-blossoms, and burning with a blue or purple flame; hence its name. It is extremely poisonous, like its product, hydrocyanic or prussic acid. By submitting it to a pressure of about sixty pounds per square inch, it may be converted into a liquid, being about the most readily condensible gas with which chemists are acquainted.

With hydrogen, as already stated, cyanogen affords the celebrated poison called prussic acid, popularly, but known, in chemistry, as *hydrocyanic acid*. This has no practical interest for the electro-metallurgist, except that an early French experimentalist in the art recommended its production for the purpose of affording a very pure cyanide of silver. He remarks—"If we take commercial hydrocyanic acid which has been prepared fifteen days, and pour it into a solution of nitrate of silver, consisting of one part of the nitrate to six parts of water, cyanide of silver will be formed; but it is more or less yellow, and much ammonia and hydrocyanic gases are evolved. On the other hand, if we make a solution of cyanide of potassium, filter it, and dissolve cyanide of silver in it, this solution, which was clear and colourless, immediately becomes troubled and black, and betrays an odour of ammonia and hydrocyanic acid." The process he recommends, excepting the formation of nitrate of silver, that has been described at p. 296, *ante*, is as follows:—

"Dissolve nitrate of silver in distilled water, and pass hydrocyanic acid [in vapour] through it, from a mixture of pounded ferrocyanide of potassium [the commercial yellow prussiate of potash used in dyeing, &c.] and sulphuric acid, diluted with twice its weight of water—continuing this as long as a precipitate will form. Wash the cyanide of silver, and preserve it below water, away from the light. Thus precipitated, the salt dissolves without residuum or colour, and gives splendid results." In respect to this, Mr. Gore advises—"That six parts of sulphuric acid should be mixed with from thirty to forty parts of water, and the mixture must be allowed to cool. Then put it into a flask [represented in the following cut], together with

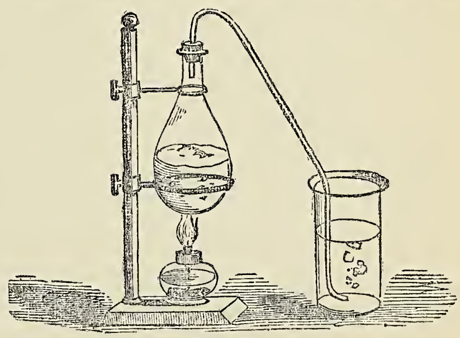
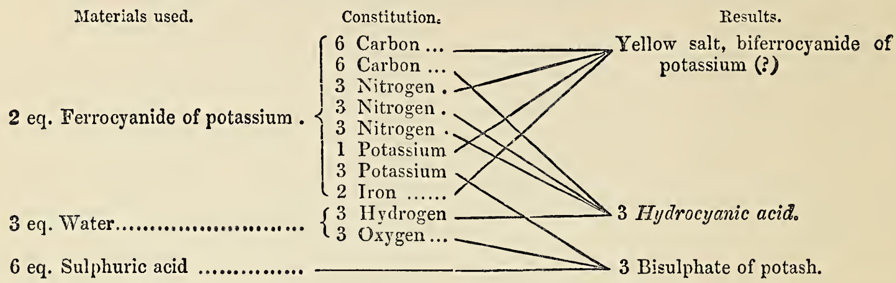


Fig. 178.

ten parts of coarsely-powdered ferrocyanide of potassium. Heat must be applied until gas [or vapour] is evolved from the mixture, or as long as a precipitate is produced in the silver solution; the gas being passed, by a tube from the flask, into a vessel holding the silver solution," as represented in the preceding engraving. The same authority justly adds, that whilst a pure cyanide may be so obtained, its economy is questionable. A yellow residuum or salt is left by the preceding operation; and the following diagram represents the results, so far as the production of hydrocyanic acid is concerned; the cyanide of silver being identical in composition with that already previously and frequently described.

Decomposition of Ferrocyanide of Potassium to produce Hydrocyanic Acid.



But, for all practical purposes, the cyanide of silver is made directly through precipitation by cyanide of potassium, as already described; and this is commercially procured, on the large scale, by the decomposition of the yellow prussiate of potash, or ferrocyanide of potassium.

The latter substance is readily procured by burning together almost any kind of animal matter, old iron, and crude carbonate of potash, by means of which a series of complicated changes result in the formation of a compound of cyanogen, with iron and potassium. It will not interest the practical reader, and will be of no benefit to him, to enter into any explanation of the changes thus produced. Suffice it to say, that after the pasty mixture, produced as above by the fusion of such ingredients, is cooled, and its soluble contents removed by water, evaporation of the solution, so effected, results in the production of the beautifully-crystallised substance commonly known as the yellow *prussiate of potash*, but, as more correctly denominated, chemically, the *ferrocyanide of potassium.*

The following methods, with many others, have been offered for the production of cyanide of potassium from the ferrocyanide.

Intimately mix, in powder, eight parts, by weight, of ferrocyanide of potassium with three parts of dry carbonate of potash, and project portions of this, successively, into a red-hot iron crucible. Keep the latter covered, to prevent access of air, except at the moment when fresh portions of the mixture are introduced. The mass will at last become completely melted. It must be occasionally stirred, to promote the thorough admixture of the ingredients, by means of a rod of iron. When, on removal, the latter is covered with a white substance, the crucible may be removed from the furnace, and the contents be allowed to settle. The top fluid portion is then to be poured off into a clean iron pan, and allowed to cool; the mixture being covered carefully during cooling, to prevent access of air, which, by oxidation, might, and, indeed, would, convert a portion of the cyanide of potassium thus formed into cyanate, carbonate, and other compounds. When cool, the mass may be broken up into fragments, and considered as available cyanide of potassium for making the cyanide of silver solution.

This method is more particularly described by Mr. Gore, as follows:—"Take ferrocyanide of potassium; pound it fine; and gently heat it in an iron pan, with constant stirring until dry; treat a quantity of the best quality of carbonate of potash in a similar manner. When they are perfectly dry, add about three parts of the carbonate to eight parts of the ferrocyanide, and thoroughly mix them. Heat the mixture rapidly, in an iron ladle or crucible, until it melts into a clear liquid, when gas will be evolved from its surface. It should be maintained at a moderate or dull red heat about fifteen or twenty minutes, or until the end of a cold iron rod, dipped into it, shows a white sample. The fusion should not be continued until the evolution of gas ceases, or the product will be of a gray colour. It should be kept covered as much as possible. By allowing it to stand undisturbed a few minutes towards the latter part of the operation, and occasionally tapping the sides of the ladle or crucible, the iron of the ferrocyanide will settle at the bottom as a fine black powder; the colourless cyanide of potassium may then be poured off into a cold iron pan, or upon a thick and cold iron plate; it should be broken up whilst still warm, and preserved in a well-stoppered jar.

"The black sediment, which contains much cyanide of potassium, should be scraped out of the vessel while still hot, and preserved, as water will at any time dissolve out the cyanide. If the process be well conducted, the product will be of a clear white colour, or, at most, but very slightly gray. A larger proportion of cyanide of potassium is obtained by this process than when ferrocyanide alone is employed, because, in the former case, one-third of the cyanogen (that which was combined with the iron) combines with the potassium of the carbonate of potash, whilst, in the latter case, it is lost; the cyanide produced by the fusion of the ferrocyanide of potassium alone is of a grayish-black colour, and is termed 'black cyanide.'"

Another source of cyanide of potassium is found in the deposit of soot, &c., that may be collected in long flues where much coal-smoke passes through. The carbon and nitrogen present in the coals afford the necessary cyanogen; and, by an ingenious series of operations, Prussian blue, ferrocyanide of potassium, and, consequently, cyanide of potassium may be obtained. Of course, this method is of no practical value to the electro-metallurgist, except so

far as it may tend to make the price of the ferrocyanide cheaper, and, consequently, lessen the cost of the cyanide production.

By the method of making this substance from ferrocyanide of potassium and carbonate of potash, many impurities result, exceeding at times one-third in weight of the cyanide resulting from the operation. Some of them are produced by the oxidating action of the atmosphere; hence the necessity of keeping the crucible closed as much as possible. By this oxidating action a portion of the cyanide becomes converted into a cyanate and carbonate of potash; sulphate of potash, and other substances also result. It is hence desirable to test the commercial value of any specimen; and this, according to two good authorities—Messrs. Glassford and Napier—may be done as follows:—

"Make two solutions, one of the given cyanide and one of nitrate of silver, each containing known weights of the salts—say one ounce of the cyanide dissolved in six ounces of distilled water in a graduated glass vessel, and 175 grains of the crystallised nitrate dissolved in about two or three ounces of distilled water; add the cyanide solution carefully and slowly to the nitrate of silver liquid, until the precipitate first formed is all re-dissolved. The quantity of the cyanide solution required to effect this (with the above quantity of nitrate of silver) will have contained 130 grains of pure cyanide; and, from the quantity used, we may easily calculate the amount of pure cyanide in the whole ounce. It is said, that 'when nitrate of silver is added to a solution of cyanide of potassium, so long as the precipitate formed is all re-dissolved, we obtain the *whole* of the cyanide of potassium in combination with the silver: none of the other salts in solution take any part in the action, even though they be present in a large proportion. This enables us to test the exact quantity of cyanide of potassium in any sample.'"

This method does not greatly differ from others already described at p. 300, *ante, et seq.*, and is dependent on the facility with which nitrate of silver precipitates cyanogen in the form of cyanide of silver, and the re-solubility of this in an excess of cyanide of potassium.

A few observations on the necessity of care in respect to the exhalation of fumes from all cyanide solutions, may not be out of place, as neglect in this respect may be productive of serious consequences.

As electrolysis of such solutions progresses, a large quantity of hydrocyanic fumes is given off, owing to the oxidation of the potassium of the cyanide forming potash, and the hydrogenation of the cyanide producing hydrocyanic or prussic acid. This latter escapes into the atmosphere, giving the strong characteristic bitter-almond odour. If only a small quantity be evolved, the smell is agreeable rather than otherwise; but in large quantities an offensive smell is produced. Yet after inhaling the vapour for some time, the sense of smell becomes deadened, and, at the same time, the nerves of the head are in part paralysed. A dull, heavy headache, coldness of the palate, languor, and sickness follow—all indicating the poisonous effects that are progressing. A remedy may be found in an occasional inhalation of liquid ammonia; but, in every instance, the fumes that are thus produced should be carried off by complete ventilation. This may easily be effected by placing, in a small establishment, the depositing-trough under a hood, that can be raised or lowered as needed. From the top of the hood a funnel should be carried into an adjacent chimney having constantly a draught upwards within it, which is easily obtained by having a small fire at the base of the chimney; or, in the absence of this, a gas-light may be burned inside the hood, to create an upper draught of hot air, and, consequently, complete removal of noxious fumes. A common error exists in supposing that a temporary removal into fresh air prevents any unpleasant consequences arising. But in one case, at least, we have found the effects of long exposure to the fumes to last some days, producing disinclination to exertion, dulness of intellect, and weakening of the digestive organs. For similar reasons the hands should not be immersed in any solution of cyanide of potassium. Serious consequences have occurred to photographers, who employ cyanide of potassium largely as a fixing agent, from its power of dissolving unchanged silver compounds in their processes.

Small surfaces, such as buttons, pins, &c., &c., may be "washed" with silver by simple immersion of them, in a wicker basket, in a cyanide solution, into which should be placed a porous pot containing a strip of zinc charged with a little weak nitric acid, this being preferable to any other, because it does not tend to produce an insoluble salt with the silver solution external to the porous pot. A wire should extend from the zinc to the articles to be plated, and forced in amongst them so as to maintain metallic contact with the zinc plate. The articles should, of course, be scrupulously clean before immersion in the cyanide; and they should also be repeatedly shook up, so as to expose fresh surfaces. By this method the silver is supplied at the expense of the solution of the cyanide; and hence it is a wasteful one; but still, for such purposes as we have named, it is at once ready, effective, and convenient.

The following curious peculiarities, showing the influence of surface and mechanical conditions generally, have been noticed by Mr. Gore. They are as follow:—

"1. If two perfectly similar pieces of thin sheet brass are taken (except that one is perforated all over with small holes), and both be simultaneously immersed in the same solution, to be silvered, and with the same battery power applied to each, the latter, although its amount of surface is reduced by the perforations, will become coated with silver much more slowly than the former.

"2. If a wire-gauze cylinder of a Davy lamp be suspended side by side with a piece of thin tubing of the same metal, and of the same dimensions, the latter will become coated more rapidly than the former.

"3. If two pieces of the same metal—iron, for

instance—be immersed, to be silvered in the ordinary cyanide of silver solution, or to be coppered in a hot cyanide of copper and potassium solution, each containing exactly the same amount of surface to be coated, but the one being in the form of a thin sheet, and the other in that of a thick plate, or solid block of metal, the former will be coated much more rapidly than the latter.

"4. The edges and points of articles, whilst being plated, exhibit a greater tendency to a crystalline deposit than the flat parts; and this tendency is sometimes manifested in depositing silver upon table-knives and forks. It is the knowledge of these, and many other peculiarities of different metals and articles met with in practical working, and of the means of overcoming their attendant difficulties, which constitutes one of the chief differences between the practical operator and the scientific man."

The recovery of silver from waste solutions is a point of practical importance to the electroplater; for, from a variety of causes, solutions will become valueless for plating purposes. Gradually, for example, the articles introduced into the liquid for plating, communicate a portion of themselves, such as of copper, iron, nickel, &c. These accumulate, and render the solution one of alloy rather than of pure silver. The rectification of a solution, also, occasionally results in failure; and all attempts to "patch it up," by the addition of more of either cyanide, are often unsuccessful. The plan is, therefore, to evaporate such solutions to dryness. Remove the solid residue to a mortar, and reduce it to powder. Weigh it, and add thereto one part of nitre, with two of common salt. Mix these intimately in the mortar, and then dry the mixture. Transfer it to an English or Hessian crucible, and fuse it, at a bright red heat, in a furnace. By such means, the silver, with the other metals the solution had contained, will be reduced to the metallic condition; and, when the crucible is cold, the metal may be removed, or it may be poured, whilst in a melted state, into water, to granulate it.

The metallic silver so obtained is too impure to be used for the manufacture of fresh nitrate of silver for direct use in preparing fresh cyanide; but the pure metal may be obtained thus:—Dissolve the silver in nitric acid; then dilute the solution considerably with water. Add to it common salt so long as any precipitate forms. The latter consists of chloride of silver only. This is to be collected, washed, and dried. If it be then fused with carbonate of potash, metallic silver, in a pure condition, will be obtained; and from this, pure nitrate, and, subsequently, the cyanide, may be produced, as already directed at p. 297, *ante, et seq.*

Another method is as follows:—"Add hydrochloric acid to the plating solution until the liquid shows a strong acid reaction. The precipitate of chloride of silver which is thus obtained will be of a reddish colour, because of the cyanide of copper which is precipitated with it when the solution has been used for silvering objects containing copper. In this precipitation by hydrochloric acid, there is hydrocyanic acid vapour largely set free; therefore the operation should only be performed in the open air, or in a place where there is good ventilation [see *ante*, p. 305]. If the precipitate be very red, it must be treated with hot hydrochloric acid, which will dissolve the cyanide of copper. The chloride of silver having been washed with water, must be dried, fused with potash in a Hessian crucible, and then covered with borax, in the ordinary manner for obtaining metallic silver.

"This method is very simple in its application, and very economical, considering that, by the aid of hydrochloric acid, *all* the silver contained in the solution of cyanide of potassium is precipitated, and there remains no trace of it in the liquid. But the large quantity of hydrocyanic gas which is disengaged, is a circumstance that must be taken into serious consideration when operating on large quantities of silver solution, the vapour of which is very deleterious; and nothing but the most perfect ventilation, combined with arrangements for the escape of poisonous gases, will admit of the process being carried on without danger to the workman. When, however, the precautions dictated by prudence are taken, the method in question may be considered as perfectly practical. The liquid should be poured into very capacious vessels, because the addition of the hydrochloric acid causes the production of a large amount of vapour."

The operation, therefore, leaves nothing to be desired in regard to the entire recovery of silver from waste solutions; but the following practical observations on the nature and cause of impurities in silver solutions, and the recovery of the precious metals generally, will be of additional value.

"When a solution of silver, prepared for silvering articles of bronze and brass, has been employed for a certain time for that purpose, the precipitate produced in it by the addition of hydrochloric acid is not pure white, but reddish, in consequence of the reddish-white cyanide of copper which is precipitated with it; for we know that those silvering liquids which have thus been used for some time contain copper in solution. The same thing occurs with the solutions for gilding, in which articles of silver, copper, bronze, and brass have been gilded for some time. The liquid contains, after a certain time of service, not only gold, but also silver and copper. This case presents itself especially when gilded articles of silver, containing copper or other alloys of silver, are in the solution of gold; then the precipitate of cyanide of gold, produced by the addition of hydrochloric acid, does not possess its proper pure yellow colour. It has happened that a precipitate of this kind, instead of being yellow, was green; and, in fact, articles of iron have been gilded in a solution, and the precipitate contained, besides cyanide of gold, Prussian blue, so as to be demonstrated in an examination; which consisted in boiling the green precipitate

in *aqua regia* [nitro-hydrochloric acid], filtering, to separate the dirty green residue, evaporating the filtered liquid to dryness, and dissolving the dry salt in water with hydrochloric acid. The addition of protosulphate of iron in solution to this new liquid gave a brown precipitate, and the salts of tin [the chloride] a reddish-brown precipitate. In treating by *aqua regia*, the cyanide of gold was then decomposed, and converted into chloride of gold."

Gold Solutions.—With the exception of platinum, gold is the most refractory of all ordinary metals. Generally its affinities for all other bodies is comparatively slight; hence it is easily reduced in the metallic state from all its solutions. With oxygen, chlorine, iodine, bromine, cyanogen, and sulphur, it forms oxides, chlorides, an iodide, bromide, cyanide, sulphocyanide, and hyposulphite; but, practically, the cyanide is alone employed for electro-gilding, as it forms, with cyanide of potassium, compounds analogous to the cyanides of silver and potassium, already so fully described.

Just as the nitrate of silver is the basis of our methods of making the cyanide of that metal, so is the terchloride of gold in relation to gilding solutions for metallurgical purposes. The method of making it is to dissolve the *pure* metal—that is, gold entirely free from copper, silver, &c.—in nitro-hydrochloric acid, or, as it is technically termed, *aqua regia*, because of its power of dissolving the noble metals. The plan to be adopted we quote from Mr. Gore. It is as follows, for making the terchloride :—

"Take a mixture of two or three measures of hydrochloric acid, and one measure of nitric acid [both of which should be strong]; make the mixture hot, and add pure grain gold to it as long as the latter will dissolve; it evolves gas whilst dissolving. When it is all dissolved, slowly evaporate the liquid until it crystallises to a dark ruby-red mass; or it may be of a yellow colour, according to the proportion of the ingredients. This is terchloride of gold, and contains one equivalent, or 197 parts, of gold, and three equivalents, or 106·5 parts, of chlorine. If it be too much evaporated, chlorine gas will be evolved, the gold will be set free, and be mixed with the salt; it will also precipitate on dissolving the salt in water. To produce the yellow chloride, mix together, in a glass or stoneware vessel, one part, by weight, of nitric acid, three parts of hydrochloric acid, one part of pure gold, and one part of water. Cover the vessel with a glass dish, make the liquid quite hot, and maintain the heat until red vapour ceases. If some gold remain undissolved, add more of the liquid mixture, and treat as before. When the vapours cease, remove the glass cover, and replace it by folds of blotting-paper. Evaporate until it crystallises, on *cooling*, into yellow chloride of gold. The red chloride is formed in the same manner, except that the liquid mixture should be composed of one part of nitric and two parts of hydrochloric acid, more being added than is necessary to dissolve all the gold. One ounce of gold will dissolve in about four ounces of the mixture; and, when crystallised into the red mass, will weigh about one ounce and 165 grains."

It may possibly happen that some of our readers will not be at all times able to procure pure gold; that is, the metal entirely free from any other metal. In such cases, either a sovereign or half-sovereign may be dissolved in the manner just stated. On adding to the chloride, so formed, water, to dilute it, and then a solution of protosulphate of iron, the gold will be precipitated *pure*, as a fine powder, which is to be carefully washed with distilled water, on a filter. Pure gold, prepared after this plan, being in a fine state of division, will dissolve in cyanide of potassium, as we shall presently remark on more fully.

It is remarkable that, whilst both gold and platinum are absolutely insoluble in either nitric or hydrochloric acids separately, each metal is readily soluble in a mixture of the two. The following paper by Mr. E. W. Bartlett, communicated to the *Chemical News* in November, 1867, very conclusively shows that it is to the evolution of chlorine in the nitro-hydrochloric mixture that the solvent power of *aqua regia* is due.

Commencing with a quotation from Turner's *Elements of Chemistry*, Mr. Bartlett observes—

"It has generally been inferred, that the power of nitro-hydrochloric acid, as a solvent for gold and platinum, is owing to the evolution of free chlorine. The proof of the inference has been this:—When *aqua regia* is heated until no more chlorine is evolved, the residual liquid is 'found to be a solution of hydrochloric and nitrous acids, that is incapable of dissolving gold.'—*Turner*. In experimenting on the electrolysation of compounds the other day, it occurred to me that this hypothesis is capable of decided proof; and this was the series of experiments. 1. Into an ordinary apparatus for the electro-chemical decomposition of water, having platinum electrodes, a weak solution of hydrochloric acid was poured. Over the anelectrode a glass tube was placed, and in this tube some gold leaf. Twelve pairs of Wollaston's double coppers were employed, excited by dilute sulphuric acid only. On completing the circuit, the penetrating odour of chlorine was very perceptible, and, in a few seconds, the gold in the tube over the anelectrode was completely dissolved; as also were the fragments that had been put into the solution outside the tube. 2. If chlorine has this power over gold, it may be supposed that the chloride of either a metal or an alkali, providing that the compound is an electrolyte, will exhibit, on electrolysation, the same result. Chloride of sodium was the substance first experimented with. A saturated solution of the salt was made; and, with precisely the same arrangement as before, the gold in the tube over the anelectrode was speedily dissolved. 3. The same result was obtained on electrolysing a solution of chloride of ammonium and chloride of barium. By a power of twenty pairs of Wollaston's double coppers, the gold was dissolved with a rapidity equal to that when a solution of chloride of sodium was the liquid

electrolysed. Both times the blue colour of litmus was quickly discharged ; but there was no previous reddening of the colouring matter to indicate the generation of hydrochloric acid. 4. A solution of chlorate of potassa was the liquid next electrolysed. With the same power of twenty plates, the gold was very gradually dissolved, though the battery was in good action. The odour of chlorine was perceptible, though fainter than in the former experiments. A solution of litmus was poured into the vessel, and a tinge of red was then perceived at the anode, owing to the action of the evolved chloric acid upon the colouring matter. The blue colour of the solution became fainter by degrees, evidently proving, that since chloric acid does not possess bleaching properties, free chlorine was evolved. Possibly this formation of chlorine from chloric acid is a secondary result of the current; but it is quite as probable, and more so, that the chlorate of potassa and chloric acid were successively decomposed by the current of electricity. I am not aware that the dissolution of gold and the influence of chlorine over the metal has been shown in this way before. True, Davy has proved that nitro-hydrochloric acid does not dissolve gold unless free chlorine is developed. Mr. Grove, also, has shown the action of chlorine liberated by the voltaic current; but in a different way. Two strips of gold leaf, one in nitric, the other in hydrochloric acid, in contact through a porous division, were connected by a gold wire : the hydrochloric acid was decomposed, and the gold in it immediately dissolved. The experiments now made may not possess the less interest because they refer to a foregone conclusion, and show that, by the decomposition of other compounds of chlorine besides hydrochloric acid, the precious metals may be dissolved."

The experiments tried by Mr. Grove, led to the discovery, by that gentleman, of the battery which is known by his name ; and that, as previously stated, is the most powerful combination, for its size, that we possess in respect to voltaic batteries.

It has been recommended that, in the impossibility of obtaining pure gold, the ordinary sovereign or half-sovereign may be employed, as a source of the metal in its pure state, by the process described at p. 307, *ante*. But if either of those coins be employed of a date antecedent to 1826, silver will be also found. Our *present* standard of gold for coinage is an alloy of twenty-two parts of pure gold with two parts of copper ; and, by following the plan previously recommended, the copper is kept in solution, whilst the gold is precipitated as a fine powder. If a coin of a date anterior to 1826 be employed as a source of gold, all silver present should be precipitated as a chloride during the solution. If, therefore, a precipitate occur in dissolving such coin, it will be chloride of silver, which should be carefully collected, well washed, restoring the washings to the gold solution, so that none of the latter metal be lost, and reducing the chloride of silver by fusing it with carbonate of potash, as already directed.

Before describing how to make the best kind of solutions for electro-gilding, it may not be out of place to say a few words in respect to the dry way of assaying both silver and gold, whether either be alloyed with copper, as in ordinary modern coin, or when the three metals are alloyed together, as in the coin produced at our Mint antecedent to 1826.

The cupellation of these metals proceeds on the principle that, by a certain amount of heat, under favourable circumstances, silver and gold will separate pure from the base metals, the latter undergoing oxidation and absorption in the *cupel*—a small conical vessel, made of bone-ash, the porosity of the latter favouring the absorption of the oxide of the base metals.

Supposing, first, that it is required to ascertain the proportion of silver in an alloy of copper, say as in the ordinary coin. About twelve grains of the silver is wrapped in *pure* sheet lead, and placed in a cupel. This is held in a muffle, which is an earthenware oven, that is placed in a furnace constructed for the purpose, and in such a manner, that whilst the cupel can be heated to any desired extent, air can pass over its contents, so as to oxidise the lead and the copper in the alloy. If the operation be properly conducted, sufficient heat and air being afforded, at the end of about twenty minutes the dull dirty appearance of the metal on the cupel will suddenly disappear, the silver will at once attain a brilliant polish and the form of a bead ; and this result, technically called "brightening," indicates the end of the process. At the same time, the fumes of oxide that had been given off also cease, at which moment a flash of light appears. The cupel is now *gradually* cooled, to prevent any loss of silver, the weight of which, when cold, indicates very nearly, but not exactly, the amount of pure silver in the alloy that has been assayed, a minute portion of the lead remaining combined with the otherwise pure silver.

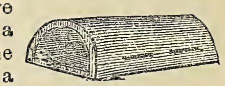


Fig. 179.

The process of assaying gold is precisely similar when copper alone is alloyed with it; but when silver is also present, another operation, called *quartation*, has to be performed. The following remarks by Dr. Scoffern explain the process :—

"Now gold is not soluble in nitric acid, whereas silver readily dissolves in that menstruum ; hence theory suggests that all the silver contained in an argento-auriferous alloy should be capable of removal by the action of hot nitric acid, leaving the gold behind. Practically, however, this result does not ensue except the silver present amount to not less than two-thirds of the total weight of the mixed metals. Hence the process of gold-assaying resolves itself into the following general scheme : the assayer having formed a judgment, from the colour and general appearance of the alloy, as to the amount of silver present, adds such a known excess of pure silver as, when fused with gold, shall yield a button, having the composition of about three parts, by weight, of silver to

one of gold. The compound is now wrapped in thin sheet lead, and cupelled in the ordinary manner; the result of which operation is a button of gold mixed with silver. This product is next flattened into a plate or ribbon, heated to render it soft, converted into a flat helix, termed a "cornet," by winding it round a quill or other small cylinder, and boiled with nitric acid. By this treatment the whole of the silver is dissolved, and the gold remains. When first withdrawn from the nitric acid the gold helix is friable, and devoid of the metallic appearance; after being heated, however, its particles cohere, and its surface assumes the golden aspect."

Such are the methods by means of which silver and gold alloys are assayed in the dry way. The plan may be equally used to obtain the metals in a sufficient state of purity to make either nitrate of silver or chloride of gold, instead of by solution and precipitation, to free them from copper. The adoption of either plan, preferably, must, however, of course, be left to the judgment, convenience, or other circumstances of the operator.

It will be hardly necessary to describe, more than by mere mention, other compounds than the cyanide of gold, which will presently be fully inquired into. The oxide is obtained by precipitation from the terchloride, through the addition of caustic potash as long as any precipitate falls. The same result arises from digesting the chloride of gold with magnesia. The precipitate must be filtered, then washed with a little dilute nitric acid, and subsequently with distilled water. Iodide of gold may be obtained by adding iodide of potassium to a solution of the terchloride of gold, when an iodide analogous to the cyanide is obtained, that is soluble in excess of iodide of potassium, but insoluble in water. The bromide of gold results from digesting gold precipitated by sulphate of iron, as already described at p. 307, *ante*, in liquid bromine. The bromide is soluble in water.

We next turn to consider the best solutions that can be employed for electro-gilding, and the various methods of making and using them.

As previously stated, the cyanide of gold and potassium, as a double "salt," analogous to that of silver, is the only eligible one for electro-deposition. It is made by the *chemical* method as follows:—"Form the terchloride of gold [in the manner already stated at p. 307, *ante*]. Then either add a cold solution of caustic potash [to precipitate the oxide], as long as a precipitate is produced, filtering and washing the precipitate with distilled water, or by digesting the chloride solution with magnesia. Filter, and wash the precipitate formed by the last process, first with nitric acid, and then with distilled water. Or add to the solution of the terchloride of gold, one of carbonate of ammonia, until a precipitate ceases to be formed: filter, and wash the precipitate with distilled water. The precipitates produced by potash, and by magnesia, consist of oxide of gold; whilst those produced by ammonia, or its carbonate, is an *aurate* of ammonia, which is a very explosive compound [and analogous to a solution of oxide of silver in ammonia]. The precipitate, after being well washed by the successive addition of distilled water, should be added, whilst still wet, to a solution of cyanide of potassium, containing the proportion of one pound of the latter to a gallon of water. Then about one-fifth more of the same [cyanide of potassium] solution should be added to form *free* cyanide. A very good proportion is—one ounce of gold, one pound of cyanide of potassium, and one gallon of distilled water.

"The wash-waters of the preceding precipitate should not be thrown away without being tested for gold, which is done by immersing a piece of bright zinc in them, and observing if it receive a yellow deposit. In that case, a solution of protosulphate of iron should be added as long as a precipitate of greenish-brown powder, which is metallic gold [see *ante*, p. 307], is produced. If this fail to precipitate the whole of the gold, a sheet of bright zinc should be immersed in the liquid, taken out occasionally, and the deposit of gold brushed off, by a hand-brush, in water containing a little sulphuric acid. [The latter dissolves away the zinc, but leaves the gold untouched.] The greater the quantity of *free* acid contained in the original chloride solution, and the larger the excess of potash, ammonia, or carbonate of ammonia added, the greater will be the amount of gold dissolved [and that, without care, may be wasted] in the washing-waters. If, when we dissolve the terchloride of gold in water, a yellow powder remain undissolved at the bottom of the vessel, it indicates that there is no free acid in the salt; but the powder may be re-dissolved by the addition of a mixture of nitric and hydrochloric acids [see *ante*, p. 307], and the application of heat."

It has already been noticed, that gold precipitated as a fine powder by the addition of protosulphate of iron to terchloride of gold, is directly soluble in cyanide of potassium. But this process affords no special advantage beyond that just described, simply because the same operations of washing, filtering, &c., must be gone through. Again, the cyanide of gold may be directly formed "by cautiously adding cyanide of potassium, dissolved in six parts of water, to a normal solution—that is, one not containing free acid—of terchloride of gold, consisting of one part of the chloride, and five parts of water, until a copious yellow precipitate settles down. If more cyanide of potassium be added, the precipitate becomes of a dirty yellow colour, and is more quickly deposited. A still larger quantity of the cyanide of potassium renders the precipitate of an orange colour. It is a crystalline powder, permanent in the air. By ignition it is resolved into metallic gold and gaseous cyanogen. It is not decomposed by sulphuric, nitric, and hydrochloric acids, nor by *aqua regia* [nitro-hydrochloric acid], unless freshly precipitated, and then only slowly. It is not decomposed by sulphuretted hydrogen [or hydrosulphuric acid]. Hydrosulphate of ammonia [that is, sulphuretted hydrogen in solution in water, saturated with liquid ammonia] dissolves it slowly, but completely, forming a

colourless solution, from which, by the addition of acids, sulphide of gold is precipitated. It dissolves in aqueous solutions of ammonia, hyposulphite of soda, and alkaline cyanides ; but not in water, alcohol, or ether. It requires about twenty-three parts of a solution of cyanide of potassium to dissolve it."

The preceding are the chief methods of making gold solutions by the chemical process ; but, as previously noticed, the battery process may also be employed thus :—Dissolve cyanide of potassium in the proportion of two pounds to ten of hot distilled water. Into this immerse a large pure gold anode, proceeding from three quart-size cells of a Smee's battery. Fill a small porous pot with the same cyanide solution, and place it in the vessel holding the latter. Insert in the porous pot, and its contained solution, a small polished copper cathode, connected by a wire with the zinc of the battery. Gradually the gold anode will become dissolved in the cyanide, and, eventually, gold will be deposited on the copper anode. When a good deposit is effected in the latter the solution is complete, and may be used for gilding purposes in the usual way. Whilst the solution is thus being made, its temperature should be kept up to 150° Fah. The proportion of gold dissolved may, like that of silver in plating solutions, vary from one to four ounces to the gallon of cyanide solution.

The cyanide gilding solution is always worked hot, and hence it must be contained in a vessel that can be kept at the requisite temperature. Glass cannot be trusted ; for although it might stand the application of heat for some time, there is always a risk of its cracking, and that without the least previous indication having been given ; consequently, the solution would be lost. The best earthenware troughs may be used, placed in an external wooden or other trough, that may be filled with hot water, or steam, to give the requisite temperature. Some employ iron troughs, with well enamelled interiors. Two circumstances have to be kept in mind in the selection of troughs for containing the gilding solution—namely, first, that the material can resist and transmit heat ; and, secondly, that it is not acted on by the liquid, which would thereby be spoilt, and, possibly, some of the gold wasted. Two cells of Smee's battery will be required, the size of the plate depending on that of the articles to be gilded, and on the extent of operations carried on in respect to the number of articles gilded in one operation ; for, of course, the greater that number, the larger is the surface to be coated.

Generally speaking, silver articles are mostly those that are required to be gilded by the electro process. When iron, tin, or lead have to be operated on, they should be first coated with a film of copper, which must be done by using the cyanide solution described at p. 292, *ante*, and not the sulphate, as the free acid in the latter solution would, more or less, act on them. In all cases gilding is rapidly effected, but should be so successively ; that is, after a thin coating of gold is deposited, the objects should be removed from the trough, washed, and brushed, and then returned to the solution. A few minutes are generally sufficient time to give the requisite amount of gold on any object. Care should be taken that the entire body of the articles be at once immersed in the solution ; because, if the gilding is done at different parts successively, a mark will, in most cases, be made that will spoil the appearance.

The regulation of the colour of a gold deposit is a matter of importance. Mr. Gore directs for this as follows :—"After having prepared the solution, work it with a large copper anode until the deposited metal begins to deteriorate in colour ; then replace the copper by a small gold anode. With the copper anode, a rich, full colour can be obtained, becoming deeper as the temperature of the solution is raised. To produce a pale yellow, a small gold anode should be employed, the liquid being kept at a lower temperature."

Another writer remarks as follows :—"The proper colour of the gilt article, when taken out of the solution, is a dark yellow, approaching to a brown. When this is cleaned with the scratch-brush [see *ante*, p. 283], it yields a beautifully rich-coloured deep gold. But if, when removed from the solution, the colour of the article is blackish, the process may be interrupted, as the article will never either brush or burnish to a satisfactory colour. Every variety of shade may be imparted, according to the strength of the battery or the temperature of the solution, the colour of the gilding being light in proportion as the solution is cool or the battery weak ; and dark, even to blackness, if the battery is too strong, and gas [hydrogen] is given off from the article. By adding ammoniuret of gold to the solution when the articles are just being put into it, a very rich dead gold is obtained. If the colour resulting from any of the processes adopted is not satisfactory, it may be improved by the following mixture, which is that followed in the old process to colour gilding or gold—namely, 3 parts of nitrate of potash [nitre, or saltpetre], $1\frac{1}{2}$ of sulphate of zinc, $1\frac{1}{2}$ of alum, and $1\frac{1}{2}$ of common salt. The articles are coated with a paste made of these ingredients with a small quantity of water, and are then placed upon a plate of iron over a clear fire till they attain nearly a black heat [that is, just before any sign of redness is apparent], when they are suddenly plunged into cold water. A very high colour is thus obtained ; and, by a variation in the mixture, different hues may be imparted." The ammoniuret, above mentioned, of gold is produced by adding liquid ammonia to a solution of the chloride of gold. It must be cautiously dealt with, as it has fulminating qualities.

Having thus described the best solutions that can be employed for electro-gilding, it is requisite that we should give some advice in respect to the recovery of gold from spoilt solutions.

In former pages, the recovery of silver from wasted or spoilt solutions has been dealt with. But, in connection with such directions, we now quote from some other papers by several German authors, inclnding Bœttger, Elsner,

Redtel, and others. It must first be noticed, that considerable difficulty occurs in entirely recovering either silver or gold from waste solutions; and these difficulties have been well explained by the authors just named.

The details of their examinations of the subject are as follow :—

"1. If we add hydrochloric acid to a solution of silver in cyanide of potassium, until the liquid exhibits an acid reaction, we obtain a white precipitate of chloride of silver, which, when submitted to heat, melts into a yellow mass. If this were cyanide of silver, the application of a red heat would have left a regulus of [or metallic] silver. The addition of the hydrochloric acid precipitates *all* the silver present in the liquid, in the form of chloride of silver."

As already stated, this is the most effectual way of recovering silver from a solution, and effects that removal in a complete manner, so that no silver in solution can possibly be detected. But—

"2. If we evaporate a solution of silver in cyanide of potassium to dryness, and heat the residue to redness until the mass is in a state of quiet fusion, and has assumed a brown colour, there remains, when we wash the mass with water, metallic and porous silver. The wash-waters, when filtered, *still contain a little silver in solution;* because, if hydrochloric acid be added to them, it will produce a precipitate of chloride of silver. In evaporating and calcining a solution of gold in cyanide of potassium, the result is the same—we obtain metallic gold. The wash-waters, acidulated with hydrochloric acid, give, when treated with sulphuretted hydrogen, a brown precipitate of sulphide of gold; and, with the salt of tin, a violet precipitate of the purple of Cassius—a proof that these liquids still contain a little gold in solution.

"3. If we pour upon finely-divided silver—for instance, silver leaf, or silver precipitated in the porous state by zinc, from a solution of silver—a concentrated solution of cyanide of potassium, at the ordinary temperature, and shake it frequently, the liquid, at the end of a certain time, exhibits silver in solution; and, by adding hydrochloric acid to it, we produce an abundant precipitate of chloride of silver. This experiment explains why, in the wash-waters of the various combinations of gold and silver with cyanide of potassium, we can still demonstrate the presence of gold and silver after the most minute separation."

It is hence evidently necessary, in recovering either metal, that its condition of cyanide should be entirely destroyed by the formation of a new combination; as, for example, a chloride in the case of silver, which is entirely insoluble in water, and, consequently, affords us a means of completely removing all trace of silver from a cyanide solution of the metal. Hence the instructions given at p. 306, *ante*, for effecting that object in regard to silver.

It has already been noticed, that plating and gilding liquids in which articles of copper, iron, &c., have been suspended, acquire portions of the baser metals, that gradually increase in quantity the longer the solutions are employed. At p. 306, *ante*, this subject has been fully examined, and directions given for detecting and removing such impurities.

With gold, as with silver, there are two methods of removing it from waste or spoilt solutions—namely, the wet and the dry methods. The following processes are eminently adapted :—

The liquid, like the solution of silver (see *ante*, p. 306), is acidulated with hydrochloric acid. Abundant fumes of hydrocyanic or prussic acid are given off; and, consequently, such precautions as are mentioned at the above page, must be attended to for the safety of the operator. A precipitate is thus produced that consists, at all events, of cyanide of gold; and, possibly, of the chloride of silver, cyanide of copper, &c., owing to the solution of minute portions of these metals from articles made of them, that have been gilded in the gold cyanide solution. These mixed precipitates are to be washed and dried, the wash-waters to be kept; for they, as just pointed out, are likely to contain small portions of gold, and are to be treated in a manner that will be mentioned presently. The mixture is then to be boiled in nitro-hydrochloric acid, or *aqua regia.* This will not affect the chloride of silver, but the cyanide of gold and copper will be dissolved out from it. The chloride of silver may be, consequently, separated by filtration, and reduced, as directed at p. 306, *ante.* The gold and copper solution is then to be precipitated by the protosulphate of iron, when it will fall down, in its metallic state, as a brown powder; and, after washing, it will be perfectly pure, and fit again for producing the terchloride, as described at p. 307, *ante.*

The wash-waters from preceding operations are then to be evaporated to dryness; and, having only pure gold in minute quantities in them, the dry residue may be fused, dissolved, and filtered, when the remaining gold will be separated as a metal on the filter in its pure state.

The dry methods are various. One is, to evaporate the spoilt gilding solution to dryness, and to fuse the solid residue in a porcelain crucible. By such means the silver and gold will be reduced to the metallic state, whilst the copper becomes united with carbon. The residue, when cool, after fusion, is to be washed on a filter, the wash-waters being saved, and treated as just directed to recover the gold. By then heating the precipitate in nitro-hydrochloric acid, the gold and copper are dissolved, and insoluble chloride of silver is formed, which may be filtered away, washed, dried, and reduced by methods already pointed out.

The solution of gold and copper, as chlorides, is to be treated with protosulphate of iron, to separate the gold, as directed for the wet plan.

Another method is, to evaporate the mixed cyanide solution to dryness. The solid residue is to be mixed with its own volume of litharge, and fused in a covered crucible, when a metallic alloy of gold, silver, and lead will be afforded. This alloy is then treated with nitric acid, of the

specific gravity of 1·2, with heat. The gold is precipitated as a metallic powder. The silver and lead remain in solution. To separate them, the solution is largely diluted with distilled water, and hydrochloric acid is added to precipitate the chloride of silver. The latter must be abundantly washed with water, and may then be reduced to afford metallic silver.

The method of cupellation for the separation of gold, silver, and copper, has already been described at p. 308, *ante ;* and may evidently be used in connection with the above process, after the metals have been recovered as an alloy with lead.

It has been recommended to evaporate the waste solution to dryness, and to mix the solid residue with one and a-half times its weight of saltpetre. The mixture is then to be projected, little at a time, into a red-hot Hessian crucible. If too much be thrown on at once, explosions will take place that would cause loss of the material. When all the mixture has been introduced, the mass is fused, and metallic gold results.

"The following process is applicable, on the small scale, with a spirit-lamp and a crucible of platina :—Evaporate the solution to dryness ; mix the saline mass with its own weight of sal-ammoniac, and heat it gently ; ammoniacal salts decompose, as we have said, the metallic cyanides, and form cyanide of ammonium, which is itself decomposed by the heat and volatilised, whilst the acid of the ammoniacal salt (the body which salifies the ammonia) combines with the metals (passed to the state of oxides), which were previously united to the cyanogen. The sal-ammoniac, then, in this case forms chloride of potassium and chloride of gold, and, if the salt contain ferrocyanide of potassium, chloride of iron in addition. The chloride of gold is easily decomposed ; the chloride of iron is partly decomposed, and leaves oxide of iron in beautiful crystalline spangles. The undecomposed portion of the chloride of iron, like the chloride of potassium, may, after the decomposition is finished (which only requires a low red heat), be washed away with water, leaving the gold in the form of a light coherent mass, and the iron in small spangles, which may be removed by mechanical means."

Such are some of the best methods that have been proposed to recover gold from old or spoilt solutions, and fit it for the preparation of new solutions. In all cases where the gold has been recovered, it may at once be converted into the bichloride by the method described at p. 307, *ante ;* or, if in a finely-divided state, may be directly dissolved in a cyanide of potassium, to form a gilding solution, as recommended at p. 309, *ante.*

The metals chiefly, if not almost entirely, deposited by the electro-metallurgists (with the exception of iron, as described at p. 293, *ante,* for coating engraved copper plates), are copper, silver, and gold; and, beyond these, little of practical interest occurs. Still it will be desirable to name some of the solutions that have been proposed to deposit such metals.

Platina Solutions.—This is the most refractory of all the ordinary metals that can be dealt with chemically. Its only solvent is nitro-hydrochloric acid, or *aqua regia.* Scrap platina (which may be purchased at Johnson and Matthey's, the eminent manufacturers of the metal) can be employed ; and the process is nearly identical with that recommended at p. 307, *ante,* for the preparation of terchloride of gold. By such a method the bichloride of platina is formed. Excess of acid is removed by cautiously heating the solution to dryness. The bichloride may then be dissolved in water, when it will furnish a yellow solution. If the bichloride be too highly heated during drying, the protochloride is produced, a heat of little less than 400° Fah. being requisite for that purpose. The protochloride is a greenish-coloured substance, insoluble in water, but soluble in hydrochloric acid, probably by the decomposition of the latter affording an extra equivalent of chlorine.

There is no doubt but that, if a good depositing liquid could be obtained, the deposition of platina by electrical action would prove to be one of the most important branches of the art. Take, for example, the necessity that exists of using a platina still in the distillation of sulphuric acid. Some of the largest makers of the latter article have stills, though of very small size, worth some thousand pounds. The size may be guessed at when we state, that platina, in that form, is worth, on an average, twenty-five shillings per ounce ; whilst the metal weighs twenty-one times its bulk of water, three times that of zinc or iron, nearly twice that of lead, and just twice that of silver. If, therefore, a good reguline deposit could be made—say on an iron or copper surface—the advantages arising in the arts and manufactures, due to the power of resistance to chemical action of platina, would be enormous. It would replace all tinning of copper vessels ; and in dyeing, pickle-making, and, indeed, in nearly every branch of chemical manufactures, a complete boon would be conferred.

For our own part, we never had the least success, of practical value, in depositing platina ; and can, therefore, offer no advice on the subject —excepting, of course, the deposition of finely-divided platina on silver plate, by immersing the latter in a solution of the bichloride, as in making the negative plate of a Smee's battery. But this is a process that a child could scarcely fail in carrying out. We shall, accordingly, quote two authorities on the subject.

"For *platinising* [as in Smee's battery] silver by simple immersion process, we may use a solution consisting of bichloride of platina, dissolved in water containing one-fourth its volume of nitric acid ; or we may use simply a very hot aqueous solution of the bichloride alone. Nearly all metals decompose the bichloride solution, and become coated with platina in it by simple immersion. For the battery process we may use solutions of the iodide, bromide, or bichloride, or the double chloride of platina and sodium. The solution of the double chloride of platina and sodium, is made by dissolving one equivalent (169·7 parts) of bichloride of platina, and one equivalent (58·5 parts) of common salt,

in water; it requires a small anode of platina, and a very weak battery, to obtain a reguline deposit. A good solution for depositing reguline platina, may also be made by dissolving bichloride of platina and common salt in a solution of caustic potash."

We have tried the above; but, as before stated, the results were practically valueless, so far as affording a protecting metallic surface of platina on any of the inferior or readily oxidisable metals; and, of course, this is the object that alone induces the use of platina, for it has none of the beauty of silver when at its highest polish; and, in this respect, is also inferior to, although it resembles, steel.

Another authority remarks—"Platina is rather difficult to be operated upon by the electric current. One great cause of the difficulty is the insoluble nature of the metal; and although there is a positive electrode [anode] used with the solution, which gives a metallic [or reguline] deposit, it is hardly acted on; so that the solution is instantly comparatively exhausted of metal. As the battery power is regulated to the original strength, it becomes, in a few seconds, too powerful; hence the metal begins to be deposited as a black powder. These, and many other practical difficulties, are in the way of an extensive application of this metal to general use by means of electric deposition. We have covered iron, copper, and brass with platina, which have stood untarnished amid the fumes of a laboratory for eighteen months; but the obtaining of such samples was attended with much labour. The solution is made by dissolving the metal in a mixture of nitric and hydrochloric acids [as previously directed], with application of heat. When evaporated to dryness, a solution of cyanide of potassium is added to the remaining mass; and after being slightly heated for a short time, it is then filtered. Even with the greatest care the operator often fails in getting more than a mere colouring of metal over the surface, and then it is not adhesive."

If we consider the electrical relations of platina, it will be no matter of surprise that such difficulties arise. It is electro-negative to nearly every other known metal, and highly so to all in ordinary use; and this fact, added to its insolubility and feeble attraction for all other elementary or compound bodies, leaves but little hope that the difficulties in electro-deposition of platina are likely to be overcome. Still we need not despair of anything in science. Ten or fifteen years ago, before Deville succeeded in producing it abundantly, aluminium was a metal so rare, that a bar of it had never been made; and the first bar that arrived in this country was of fabulous value. Now, the lowest kind of jewelry is made of it; and it is abundantly produced as a metallurgical product, applied to numerous useful and ornamental purposes.

Palladium Solutions.—A greater degree of success attends the attempt to deposit palladium. As a metal it partakes of many of the properties of platinum, especially as resisting most chemical agents. It is soluble in nitric acid; but *aqua regia*, or nitro-hydrochloric acid, is the best solvent. Cyanogen has a great affinity for palladium; so that when a soluble cyanide, as that of potassium, is presented to a neutral solution of palladium, the cyanide of the latter is produced. Indeed, so great is the affinity of cyanogen for the metal, that it exceeds the affinity of mercury and cyanogen, and enables us to separate it readily as a cyanide from gold and platina. It has numerous uses in the arts, and for constructing beams for balances, that are not acted on by laboratory fumes; for artificial palates, in place of gold, it is used by the dentists; and in constructing graduated scales, by the instrument-makers—all these uses depending on the difficulty of oxidising its surface by moisture, air, and ordinary chemical agencies.

Not having had much personal acquaintance with the deposition of the metal, we shall avail ourselves of the two authorities already quoted, in respect to the deposition of platina. Mr. Gore remarks—"A solution of double cyanide of palladium and potassium may be used for depositing palladium. It may be made by chemical means, by dissolving palladium in nitric acid, precipitating the solution by a solution of cyanide of potassium, washing the precipitate, and dissolving it in a solution of cyanide of potassium to saturation, and then adding a little free cyanide; or it may be easily made by the battery process, by passing a current through a large palladium anode in a solution of cyanide of potassium, until a clean smooth cathode receives a good deposit. This is an excellent solution for depositing reguline metal; it acts upon the anode with uncommon energy, conducts freely, and deposits plenty of reguline metal: a thin deposit of palladium, obtained in this solution, has been used for fixing Daguerreotype pictures, instead of gold, and is said to give them a finer tone."

One other authority states—"Palladium is a metal both easily and economically deposited; and were that metal to be had in sufficient quantity, it would make an excellent coating for lamp furniture and other objects; but, from its scarcity, palladium is too expensive for ordinary use; and it wants the beauty of silver and gold for superior purposes. To prepare the solution, the metal is dissolved in hydrochloric acid. The solution is then evaporated to dryness, and cyanide of potassium is added till the whole is dissolved. The solution being then filtered, is ready for use. The best application of this metal would be the protection of other metals from the action of acids; and, for this purpose, a tolerably thick deposit is required."

We have thus enumerated the best methods of dealing with all those metals that have little attraction for ordinary chemical agents; and now refer to the description of solutions of other metals that, more or less, stand in the same category as copper and iron, already previously described.

Nickel Solutions.—Nickel is a metal to the deposition of which we have devoted much time and trouble, with a considerable amount of success, although the practical value of the result did not tend to much benefit. Great

difficulties are presented; first, in getting the metal sufficiently pure, and next in reducing it to a form that can be adapted as an anode, for it is infusible, except at a heat almost equal to that which would melt even wrought-iron. Being desirous of obtaining about three ounces in such a condition, and after desiring several operative chemists to melt that quantity, and, if possible, reduce it to a flat plate, and the request being respectfully declined, Messrs. Johnson and Matthey kindly assisted us out of the difficulty; but they found the metal so refractory, that it cost ten shillings to fuse the small quantity into a button, in which form it was all but useless. Again, all the specimens that we could obtain in London were so impure, being loaded with copper, &c., that the cyanide solutions were soon replete with copper, and generally as rapidly spoilt.

The ordinary mode of reducing it from its ore is as follows :—

"Nickel is isolated from the arsenic with which it is associated in its various compounds, thus :—The ore is first dissolved in a mixture of dilute nitric and sulphuric acids. The nitric acid converts the arsenic into arsenious acid, and nickel being changed into oxide of nickel, unites with sulphuric acid, and forms sulphate of oxide of nickel. The liquor is now evaporated, when most of the arsenious acid crystallises, and is deposited. Carbonate of potash is now added, and the solution being crystallised, yields a double sulphate of nickel and potash. This salt may at first be slightly contaminated with arsenic, iron, and copper; by solution and crystallisation twice or three times, it may be completely freed from the former metal. Copper may be separated by precipitation with hydrosulphuric acid (which neither throws down iron or nickel); and, finally, nickel oxide may be obtained free from oxide of iron by the action of liquor ammoniæ, which dissolves the former, but leaves the latter intact. Oxalic acid precipitates the oxide of nickel from its ammoniacal solution in the condition of oxalate of nickel; which, being heated, leaves metallic nickel."

But by this method the nickel is only produced as a powder, quite unfit to form an electrode, although it may be at once dissolved to form the nitrate. To convert it into a metallic button, "portions of dried oxalate are to be rammed into a charcoal-lined earthen crucible, and exposed for not less than two hours to the strongest blast of a smith's forge. Metallic nickel may also be obtained in a spongy state, by transmitting a current of hydrogen gas over oxide of nickel, heated to redness in a porcelain tube; or in the condition of metallic button, by exposing the oxide, mixed with sugar, starch, charcoal powder, or other carbonaceous materials, to the highest heat of a smith's forge in a charcoal-lined crucible. Nickel produced by the operation last mentioned is *carburetted*; or, in other words, holds in combination a small portion of carbon; it therefore has the same relation to pure nickel that cast-iron and steel have to pure iron."

We attempted to get over the difficulty of procuring it in the form of a flat plate, by soldering small squares of the commercial nickel on one of German silver, completely coating the latter with a non-conducting substance, to prevent the action of the depositing liquid on it. So long as this was prevented, the deposition of nickel went on satisfactorily; but as no substance that can be so applied long resists the action of the potass produced in cyanide solutions, of course the plate became gradually uncoated, and introduced copper, zinc, and nickel (the constituents of German silver) into the depositing solution which we employed, that will be shortly described.

Before detailing the method that we adopted to deposit the metal, we may properly quote the following observations of the able electro-metallurgist to whom we have so frequently before been indebted :—

"The nitrate of nickel solution may be formed by dissolving nickel in nitric acid slightly diluted with water, and, when dissolved, diluting with additional water; it is a solution which does not yield its metal freely. We have deposited nickel, in the state of reguline white metal, from a solution of the double chloride of nickel and ammonia, by making a lump of metallic nickel the anode in a strong aqueous solution of sal-ammoniac, and passing a strong current of electricity through it for several hours, until the liquid acquired a pale greenish-blue colour. We have also obtained a similar deposit by treating a solution of one part of arseniate of potash, and five parts of water, in a similar manner. It has also been deposited from a solution formed by dissolving pure nickel in nitric acid, then diluting and precipitating it by a solution of carbonate of potash, or cyanide of potassium; washing the precipitate, and dissolving it nearly to saturation in a solution of cyanide of potassium, and operating upon this liquid, by the battery process, with an anode of pure metal. Its appearance, when deposited from this solution, is said to be nearly equal, in whiteness, to silver; and its deposition has been proposed to be applied to the production of an inferior class of plated articles."

The method that we succeeded in was that last described, with certain modifications. The nitrate of nickel, if purchased at the operative chemist's, is sold at an enormous price—about 2*s.* 6*d.* per ounce—that renders its employment exceedingly expensive. In fact, it is so deliquescent that it can only be kept in the crystal state in a closely-stoppered vessel—the least exposure to the atmosphere turning the crystals to liquid. If, however, the process previously described for producing pure nickel or a powder be employed—by calcining the oxalate—and the reduced metal be dissolved in nitric acid slightly diluted with water, the pure nitrate is readily obtained in solution. It should then be heated, to drive off all excess of nitric acid; and, when this is effected, it is allowed to cool.

Cyanide of potassium is then added; and the cyanide first precipitated is re-dissolved. About the same proportions of metal, cyanide, and free

cyanide may be adopted, per gallon, as directed for silver at p. 298. We worked with about two ounces of nickel to the imperial gallon.

The difficulties in respect to the anode have been already recounted; but with a button weighing about three ounces, or, rather, a cone an inch and a-half wide, and an inch high, soldered to a wire, deposition can be effected. The metal should be moved about, so as to successively face each part of the receiving surface. In our experiments, a polished plate of copper, of the size of 12 × 8 inches, was thus coated with a beautiful polished surface of nickel. The battery employed was two of Bunsen's or Grove's batteries, the reguline plate in each cell exposing twelve square inches of active surface.

But the whole affair is difficult of management. The anode is apt to become coated with an insoluble crust, or one, at all events, that is with difficulty removed. A temperature of 65° was employed. By long-continued action, a thick coat may thus be obtained that has an astonishing resistance to wear and tear, and well preserves its polish in the atmosphere.

However, in 1880-81, the deposition of nickel became not only an accomplished fact, but one of most extensive application. The sulphate and other salts were patented, and at last the process of coating other metals by nickel, in many cases replaced electro-plating. A company was formed in the North of England, which undertakes such work as coating the brass and other fittings of locomotives and machinery generally, metallic clocks, and a host of other articles. The appearance of the nickel thus deposited is beautifully white, and the polish is retained for an almost indefinite period. The surface is scarcely liable to oxidation, and consequently of great value for many purposes, where the cost of silver, etc., would prevent its use.

Tin Solution.—The uses of tin, as deposited by solution or heat on the surface of copper and iron, are extensive and valuable. Copper, by thus being coated, is prevented from becoming dissolved, and hence producing dangerous results that would occur if culinary vessels were made of uncoated copper alone. If, however, any portion of the tinned surface lose the tin coat, a voltaic action commences, and the uncovered copper becomes rapidly dissolved. A curious instance of this came under our notice some years ago. A large ham had been boiled in a tinned copper vessel, from some portion of which the tin had worn off. When the ham was "done," it came out of the pot completely green, owing to the quantity of copper that had been dissolved. Many serious accidents have occurred from similar causes, especially in the making of pickles and preserves in copper or brass vessels; the acids of the fruit, in the one case, and the vinegar in the other, dissolving off the copper, and forming soluble salts of that metal.

If, therefore, tin could be deposited easily by electro-chemical action, its application in this way would become very valuable; but numerous difficulties stood in the way. We have succeeded frequently in depositing reguline tin by voltaic action. The metal so produced, when polished, retained that condition for some time, and also was capable of resisting friction of hard substances, such as sand-paper. On the small scale, the plan we adopted so far answered; but great care was required to effect the result. For objects exposing a surface of 144 square inches, we employed one cell of a Daniell's battery, exposing an equal surface of copper, and charged in the usual manner. Two cells afforded too much intensity and evolution of gas at the cathode, with deposition of rotten metal. The solution was made by the battery process. One part of sal-ammoniac was dissolved in about fifteen or twenty of water, to which was added hydrochloric acid of the ordinary commercial strength, to the extent of one-fourth part of the weight of sal-ammoniac. A large anode, a flat bar of tin, was immersed in the solution, and an inch or two of No. 16 copper wire, as the cathode, both attached to a single Daniell's cell. After some time the copper wire became coated with a brilliant film of tin, and then the article to be coated was immersed.

Gradually, however, such a solution undergoes change; a large quantity of the hydrated oxide of tin becomes separated. And, not only so, the deposited metal tends to form bunches of flat crystals of the most beautiful shape, which, when once commenced, spread with astonishing rapidity through the liquid, and may be obtained in large masses, some of the crystals measuring a foot in length. Their appearance is very ornamental; and if removed from the liquid, and washed with distilled water, they preserve their polish for an almost indefinite time.

Tin is readily dissolved, by aid of heat, in hydrochloric acid, forming the protochloride. We have used this hot, as a depositing liquid, and succeeded in throwing down the metal; but, generally, a film of pulverulent tin is produced at the same time, that covers the reguline metal first deposited on a receiving surface. On removing the article, brushing and washing it, and, by re-immersion, repeating this frequently, a successive series of reguline deposits may be obtained; but this is a troublesome process.

Most experimentalists confirm the above results, and do not recommend the chloride as a depositing liquid. Mr. Gore mentions the stannate of potash—tin being, by oxidation, converted into stannic acid. He says—"The stannate of potash solution is easily formed, either by dissolving the crystallised salt in water, or by dissolving freshly-precipitated peroxide of tin, whilst still moist, in a boiling solution of caustic potash." The peroxide is easily obtained by the action of strong nitric acid on tin; it should be filtered and washed, and may then be used as above. In this condition it is stannic acid; and, by boiling with caustic potash, forms the stannate of that alkali. The solution may also be easily formed by the battery process, "by passing a strong current, by a large tin anode, through a strong and boiling solution of caustic potash, until a small cathode receives a free white deposit. This solution, if worked at

150° Fah., yields a good deposit of fine white metal; but it decomposes by exposure to the atmosphere, and soon deposits all its metal as oxide of tin. A solution of cyanide of potassium and tin has been proposed as a depositing liquid; but it is a bad conductor with a tin anode, even if hot, and does not dissolve the metal freely."

M. Roseleur patented the following:—"For coating zinc, iron, copper, and many other metals by the battery process—dissolve 11 ounces of pyrophosphate of potash, or soda, in $17\frac{1}{2}$ pounds of water; then add $4\frac{1}{2}$ ounces of protochloride of tin, and operate by the battery process with an anode of tin. By this process the inventor says that he can tin metals beautifully, and to any thickness. Pyrophosphate of soda is easily formed by heating to redness the common diphosphate of soda."

We have not tried this method; but may state generally, that all solutions of tin intended for electro-deposition have the common fault of want of permanency. The metal has a tendency to fall down as oxide from the solution, causing great inconvenience, loss, and uncertainty.

By a kind of single-cell process, and the following solution, M. Roseleur states tin may be deposited:—"For depositing tin upon lead, iron, steel, copper, or brass, by connecting the articles with a piece of zinc, and immersing them in the solution—dissolve $10\frac{1}{2}$ ounces of bitartrate of potash [cream of tartar, or argol] in $17\frac{1}{2}$ pints of water; then add three-quarters of an ounce of protochloride of tin, and boil it a few minutes. The articles to be coated are immersed in the solution, in contact with a piece of zinc of proportionate size." A solution made of $17\frac{1}{2}$ ounces of ammoniacal alum in 22 pounds of boiling water, with one ounce of protochloride of tin, will, according to the same authority, readily coat the preceding metals by simple immersion in it.

Recently, great success has attended some patents that have been taken out for coating vessels of other metals by the electro-deposition of tin. In the ordinary way, "tinned" vessels are made of thin sheet-iron dipped into melted tin. The plates sold for making cans, etc., and a great variety of articles, were thus produced. But now the electro-deposition of tin is an accomplished and successful fact. We have seen vessels thus coated which have a brilliant white polish like that of silver. Of course, this surface being pure tin, is not easily oxidisable.

Antimony, Bismuth, Cadmium, and Cobalt Solutions.—None of these are of any practical importance in the operation of electro-metallurgy, and the three last-named may be dismissed with simple mention. Antimony solutions of different kinds have been recommended. The chloride deposits and conducts well, and the solution may be formed in the usual way by the battery process, using a large anode of antimony in strong hydrochloric acid as the liquid, the current being produced by eight or ten cells of Daniell's or Smee's batteries. Another solution—that of the mixed chlorides of antimony and ammonia—may be made by the battery process. One measure of a saturated solution of sal-ammoniac is mixed with one of hydrochloric acid, or one of commercial chloride of antimony, technically called butter of antimony. A large anode of the latter metal is employed. The solution thus afforded yields good reguline antimony.

Another solution, recommended by Mr. Gore, is as follows:—

"The potassio-tartrate of antimony is a salt not very soluble in water; its aqueous solution is a very bad conductor of electricity, and is not to be compared to the chloride for depositing purposes. We have never been able, either with strong or weak batteries, to deposit from it anything better than a small quantity of antimony in the state of a perfectly black powder: on the other hand, its solution in hydrochloric acid (which dissolves it very freely), or hydrochloric acid and water, is by far the best that we have tried for depositing antimony: it is an excellent conductor of electricity; it is not impaired by long working or exposure to light or the atmosphere (we have deposited antimony from it constantly during many months); it will bear a great amount of battery power without the deposit passing into the state of a loose powder; it deposits reguline metal very rapidly, and in great thickness. We have obtained such deposits from it upwards of two inches in thickness; articles immersed in it wash clean in water alone, without the previous use of hydrochloric acid. It may be made by mixing together about two pounds of water, four pounds of hydrochloric acid, and eight pounds of potassio-tartrate of antimony; a greater proportion of water may be used if desired."

The chloride or butter of antimony is readily formed by digesting one pound of the commercial black sulphide of antimony in four pints of hydrochloric acid, with constant stirring. When solution is fully effected, the liquid is to be evaporated until only two pints, by measure, are left. It is then to be filtered, and kept in a stoppered bottle.

So far as we are aware, no practical use has been made of the deposition of antimony. It is very easily deposited in the metallic state; and thus much resembles highly-polished steel. It, however, possesses no special advantage over other metals in this respect; and, consequently, has not been used for such purposes. The deposit of iron by Joubert's process (already described at p. 293, *ante*), is far to be preferred for any of the purposes to which antimony can be applied.

Some curious properties of the newly-deposited metal are thus described by the authority just quoted. He remarks—"If, during any part of the time the deposit is progressing, the deposited antimony be taken out, and struck gently, or rubbed with any hard substance—such as metal or glass—an explosion will occur, accompanied with a small cloud of white vapour, sometimes with a flash of light, and nearly always with considerable heat, sufficient to burn the fingers, melt gutta-percha, burn paper, and even scorch deal wood to a brown colour, especially if the

deposit be thick. This is invariably accompanied by fracture of the deposited metal; sometimes, when the process of deposition has been interrupted, and the deposited metal is not homogeneous, the fracture extends through the metal to upwards of one-eighth of an inch in depth. This phenomenon has been observed many times, both before and since its first publication : in several instances the explosion was produced even in the liquid, by striking the deposit against the glass vessel which contained it; and, in one instance, it occurred after the metal had been well washed with dilute hydrochloric acid, dried, and had remained out of the liquid several hours.

"On one occasion, a deposit had been well washed, dried, and out of the solution many hours; and a friend, in course of conversation, was unconsciously breaking small portions of it with his fingers, when it became suddenly heated, exploded, causing a slight noise like the lightning of a congreve match, and burning his fingers. In other cases, a deposit has been progressing, and has been removed an instant for examination, and the battery liquid strengthened by the addition of acid : upon examining the deposit a few hours afterwards, it has been found cracked in various directions, as if an explosion had occurred in the interval, although the apparatus had been undisturbed. A French writer has suggested that this deposit is a compound of antimony and hydrogen; and from the fact that the explosions occurred when the metal was depositing rather rapidly, we are inclined to think his explanation correct; the extra power, as we have seen in other cases, causing hydrogen deposit, which, in its nascent state, instead of being evolved, might combine with the metal and form an explosive compound. Another suggestion we would make is, that the metal may be deposited in a peculiar condition of unequal tension, similar to that of unannealed glass, and that, by breaking the closer aggregation of the particles, may develop light and heat.

"Another peculiarity in depositing antimony from the potassio-tartrate solution is, that if the solution be a very dense one, and the process long continued without disturbance of the liquid, the deposit occurring upon the cathode will slowly spread out in the form of a thin sheet upon the surface of the liquid, until it touches the anode; whilst the deposit beneath progresses very slowly. We have a button of antimony formed in this way upon a vertical copper wire, one and five-eighths inches in diameter, the deposit beneath the surface of the liquid having been only half an inch thick; it occupied about eighteen days, with a small cell of Smee's battery, in forming. Deposits of antimony formed in the above solution do not spread over black-leaded surfaces of gutta-percha, nor do they adhere, with any great degree of firmness, to copper, brass, or iron."

Arsenic Solutions.—This metal, in many of its relations, resembles antimony, especially in that of its power of combining with hydrogen, forming arseniuretted hydrogen, which is analogous to the antimoniuretted hydrogen, resulting from a combination of antimony and hydrogen. Practically, arsenic is of no interest whatever in electro-metallurgy, in respect to its metallic relations. In toxicological examinations, electro-deposition of the metal is adopted in a way first proposed by Reinsch. The matter under examination is first digested with hydrochloric acid, into which strips of pure copper are introduced, and boiled. The arsenic is then deposited as a white coating on the copper. Other applications of the electric current have been made for similar purposes; but such do not come within the scope of this work to detail, as they belong solely to analytical and medical chemistry.

Zinc Solutions.—It would naturally be expected that the enormous use of this metal in electro-metallurgy, might have led to the discovery of some process by means of which it would be deposited in the reguline state; but until recently, it had, for most practical purposes, not been arrived at, yet has at last become a great success.

The ordinary method of "galvanising iron," to protect its surface from action of air and moisture, is only galvanic in name, but not in nature. It consists in coating the iron by immersion in melted zinc; and it is in this way that the galvanised iron of commerce is commercially produced. The result is, that, for a long time, the zinc surface effectually protects the iron under ordinary circumstances. But, in some cases, such a method is ineffective from peculiar causes. A striking instance of this might have been seen, some years ago, at the Stepney station of the Blackwall Railway, near London. To prevent sparks flying from the engine chimney on to inflammable property, including shipping, &c., below the roadway of the line, it was, for some distance, roofed with zinc-covered, or galvanised iron. In the course of years, the acids generated by the combustion of the fuel in the locomotives, completely ate away the roof in a line, beneath which the escaping gases and steam impinged on the metal roof, which was completely destroyed. Under most other circumstances, however, this method is effective.

There are two great objections to it, arising from the following causes. The zinc not only coats, but actually soaks into the iron, and so renders it extremely brittle. We have frequently broken a six-inch nail by the hands, so completely had the tenacity of the iron been destroyed by the "galvanising" process. Again, it makes the iron greasy or slippery, and hence prevents it "taking hold" of an object. This, of course, is a serious objection to the application of the process to covering nails, as the following amusing instance will show, and for the accuracy of which we can vouch for, having been concerned in the matter. The then executive of the Ordnance department in London, arrived at the conclusion that a great waste of mop-sticks occurred through using the common iron nail to affix the mop to the stick. It was accordingly determined to adopt the galvanised nail, and several thousands of mops, so "nailed," were sent in by the contractors, and sent out by

the Ordnance and Admiralty Boards. Shortly after first use, the zincked nail having no adhesiveness to the wood of the stick, the mop, on being trundled, flew out of the stick, and, doubtless, became a source of indigestion to the numerous sharks that follow in the wake of a vessel.

Several years ago, however, Messrs. Elkington adopted the sulphate for deposition of zinc by the voltaic current. The solution they patented was composed of one or two pounds of the crystallised sulphate dissolved in a gallon of water. The iron to be coated, formed, of course, the cathode, and a zinc anode and one battery cell answers for effecting the deposition. By this method iron may be readily coated with zinc; and nails, &c., so prepared, have not that slipperiness just stated to be produced by the process of "galvanising."

Another advantage arising from this method is, that *pure* zinc is so deposited. By the "galvanising" plan, zinc loaded with impurities is communicated to the surface of iron. Now, it is well known that even sheet zinc, of the best kind, must be amalgamated before it can be employed in acid solutions for voltaic purposes. But in "galvanising," the crude spelter of commerce is used for the sake of economy, and it contains iron, arsenic, &c., that all render it liable to oxidation and destruction, especially if in contact with iron, which, under all ordinary circumstances, is negative to zinc, and, consequently, hastens the destruction of the latter.

The reason why "galvanised" iron, and ordinary sheet zinc, undergo destruction in the atmosphere, is ably detailed in the following epitome of some portions of a paper read several years ago by Mr. Pellat, at the Institution of Civil Engineers. After pointing out how readily iron is acted on by atmospheric causes, whether of air or moisture oxidation, he shows that "tinning" it by the ordinary methods is only a temporary expedient; and that, after a time, the tin becoming negative to the iron, hastens the destruction of the latter—a fact too familiarly known in household experience, and that has led to the substitution of other materials in making culinary articles. The following summary of his remarks, quoted from the *Imperial Journal of Art and Science*, states fairly the facts and science of the points here alluded to:—

"The tin being electrically negative to the iron, renders it a means of destruction, instead of protection, when any part of the iron is exposed. By the laws of electricity, when metals are in contact, the negative metal is protected at the expense of the positive: circumstances, such as different chemical menstrua, may alter the relative electric states of metals; but, under all ordinary circumstances, this rule holds good; and zinc being the positive metal, it becomes in consequence a protector to the negative metal iron. This electrical property of zinc, in connection with iron and other metals, has induced those to whom it was known to recommend it as a coating. The difficulty hitherto has been the obtaining of zinc pure, and the application of it without injuring the texture of the iron. From the known qualities of zinc, it has been lately much employed for various purposes, but has entirely disappointed the expectations formed from its properties. The reason of this is, that no zinc of commerce is pure, and that the impurities existing are destructive to it from the electrical law we have alluded to. The impurities existing, more or less, in all zinc, are lead, iron, arsenic, and one or two other metals, all of which are electrically negative to zinc—the consequence being that every atom of impurity, in connection with the zinc, forms a galvanic battery: thus a battery of many thousands, or rather millions, of pairs of plates is formed, the impurities being protected, and the zinc destroyed. It has no doubt surprised many who have made use of zinc, to find it, in a few weeks or months, according to circumstances, perforated with small holes, and completely destroyed. We say according to circumstances; because the *ordinary time* zinc lasts, depends, not only on the amount of impurities contained in it, but also on the exciting fluid to which it is subjected. Exposed to the action of water from the atmosphere, the destructive influence operates comparatively slowly; but, with more exciting fluids, very rapidly. Thus, a roof erected in the neighbourhood of a vinegar distillery was completely destroyed in six weeks [see our remarks on the roof of Stepney station, at p. 317, *ante*]; and vessels used for dairy purposes have lasted but a very short time, owing to the presence of acids—these causing a rapid galvanic action between the zinc and its impurities. It is, then, quite evident, that impure zinc, being itself valueless, cannot afford protection to any other metal. Now, the only process formerly in use for the coating of iron with zinc, was that of immersing the iron in melted zinc; and this we conceive open to many objections. The iron, by this process, being raised to a temperature of at least 800°, causes it to combine with the zinc, forming an alloy on the surface, which changes its state, and becomes brittle. But, upon this subject, we shall refer to the report made by M. Dumas to the French Academy. He says, 'The zincking of iron, made by steeping iron in a bath of melted zinc, has many inconveniences; besides, the iron combining with the zinc, constitutes a very brittle superficial alloy; the iron loses its tenacity—a circumstance which is not perceived, however, except in trying to zinc fine iron wire, or very thin plate: besides, the surface being covered with a layer of not very fusible metal, is always ill-formed. Thus, fine iron wire cannot be zincked by this process, as it becomes fragile and deformed; bullets cannot be zincked, as they become misshapen, and no longer of the same calibre.' We have reason to believe, that very nice manipulations, and annealing the iron after zincking, may remove some of M. Dumas' objections to this process; still, two fatal objections, in our opinion, would exist to its use: first, the impossibility of obtaining *pure* zinc, except at an enormous expense, the only process being sublimation or distillation; and, secondly, the impossibility of retaining its purity during the

process of applying it to iron. Setting aside the fact of an alloy of iron and zinc being produced by the action of heated iron immersed in melted zinc, the presence of foreign matter necessary to retain the zinc in fusion, renders it impure; these matters forming less fusible compounds, and zinc being very volatile, a great amount of waste is created."

The sulphate of zinc seems to be the most eligible salt that can be employed for electro-deposition. Most zinc salts are soluble in water; but none offer greater advantages than the sulphate, which should be neutral; because any free acid would at once attack iron in process of coating with it, and the deposit so formed of zinc would be valueless for the purposes to which it is alone applied.

An interesting subject, partly in connection with electro-metallurgy, is that of the protection of the hulls of vessels from the action of sea-water, in the case of iron hulls and copper-bottomed wooden vessels, and the prevention of the adhesion of mollusca, and other marine animals, seaweed, &c., &c. But into this we cannot enter. It will be in the memory of our readers, that Sir Humphry Davy, years ago, proposed to protect the bottoms of copper-covered vessels by affixing zinc plates, which, being positive to the copper, would undergo solution, the copper being thus protected. But the evil of adhesion then became increased; for the unprotected bottom gradually cleared itself of mollusca, &c., as the copper became acted on by the chlorine of the sea-water. When, however, the copper was protected, the adhesion of mollusca and weed became enormous.

Since the extensive employment of iron in ship-building, the question of protecting the hull has become highly important. It was stated, at a recent meeting of the British Association, that the annual depreciation of our navy and commercial ships built of iron was immense, owing to the amount of action on the metal by sea-water; and that the extra cost of coal in overcoming the loss of speed caused by adhesion of animal and vegetable matter, was alarming. The fast mail-boats between Holyhead and Dublin, have, in the course of six weeks, with the same exercise of steam-power, their speed diminished by about 25 per cent.: or rather, towards the end of six weeks, after the bottom has been scraped, 25 per cent. more coal is required to maintain the speed as demanded by the mail contract. The loss to the country must, therefore, be very great from these causes.

At the meeting just referred to, a paper was read from Mr. Daft, showing the great success he had arrived at by protecting iron hulls through attaching plates of zinc to them. Some specimens of iron plate, so protected, have remained perfectly bright after many months immersion in the sea-water at Gosport; and, altogether, his proposed method seemed to promise undoubted success.

Amongst some of the earlier schemes propounded in respect to the application of electro-metallurgy to purposes similar to those above mentioned, were coating the bottom of a wooden ship by docking it in a "sea" of sulphate of copper, and of zincking the bottom of an iron ship in a similar manner. It is scarcely necessary to add, that although, theoretically, both methods ought to succeed, the practical difficulties of carrying out the plan were insuperable. But, from many years' experience of inventions and inventors, we are prepared to hear any amount of extravagance in propositions from such quarters. The only wonder that can be excited is, how such persons succeed in duping others, and in wastefully—nay, sometimes fraudulently—sinking capital, time, and labour that might otherwise be beneficially and profitably employed.

Lead Solutions.—In respect to the metal lead, little need be said. Iron has been covered by it through electro-deposition; but the two metals barely adhere; and so soon as any portion of the iron surface becomes uncoated, the destruction of the latter metal is rapidly hastened, for the same reason that such a result occurs with tinned iron.

The ordinary soluble salts of lead are the acetate and nitrate. The former is the "sugar of lead" of commerce, and is abundantly prepared for various purposes. Lead may be deposited from either of these salts, or from a plumbate of potash, produced by dissolving litharge in a boiling solution of caustic potash. In the latter solution lead is precipitated on zinc and tin articles (but not on iron) when they are immersed in it. But the electro-deposition of lead offers no advantage, as the metal is readily obtained in any degree of thickness, for all the purposes to which it can be beneficially employed, by mechanical operations, that, from the softness of the metal, are easily and cheaply accomplished. Again, it is impossible to obtain anything like a thick regular coat of metallic lead by any known process of electro-deposition. It has the additional objection, if deposited, of adding weight to an object, whilst no extra strength is afforded.

We have thus described the solutions of the simple metals that can be employed advantageously, or otherwise, in electro-metallurgy, and shall next turn briefly to those solutions by which it is proposed to deposit alloys. We have omitted notice of mercury; for it so readily forms amalgams with most of the metals as to make electro-deposition quite unnecessary for its management. Its nitrate, cyanide, &c., have already been frequently under notice.

Alloy Solutions.—These solutions are oftener of scientific than practical interest, simply because all the results obtained by them are more cheaply and better afforded by melting together the materials intended, or used, to compose the alloy. At p. 291, *ante*, some general laws have been enunciated in respect to depositing from alloy solutions. There it has been stated, "That when the current is weak in a liquid containing two or more metals in solution, with a wire or other piece of the metals immersed as anodes in the liquid, the least positive of the substances is alone de-

posited. But if the power [of the current, or its electro-motive force] be sufficiently increased, and there is only a small proportion of the less positive substances present, the more positive substances, even though they are much more positive, will also be deposited. Thus the weaker affinities are overcome first, and to the greatest extent; the current of electricity exercising its influence first, and in the greatest proportions, upon the salt of the least positive metals."

Such must be the basis of operations in making an alloy solution, for reasons assigned at the page referred to antecedent to the above quotation. But in putting such principles into practice, many difficulties must necessarily arise that will have to be dealt with personally by the electro-metallurgist, especially in reference to the proportion of each constituent of the mixed solutions, the battery power employed, and the size of the anode and cathodes, or dissolving and receiving plates, actually and comparatively.

Ruolz was amongst the earliest to discover a means of depositing brass, which he effected from a depositing liquid of the cyanide of zinc and copper, dissolved in cyanide of potassium. In 1849, Messrs. Russel and Woolrich took out a patent for the deposition of brass. The solution they preferred was made thus :—

"Take 10 pounds of acetate of copper, 1 pound of acetate of zinc, 10 pounds of acetate of potash, and 5 gallons [50 pounds] of hot water. Dissolve the salts in the water, and add as much of a solution of cyanide of potassium as will first precipitate the mixture [that is, the mixed cyanide of the metals employed], and re-dissolve the precipitate. In addition, add about one-tenth of cyanide of potassium. Use a brass anode, or else two anodes, one of zinc and one of copper."

The above solution will have, at least, one objection to it—that of containing much free acetic acid; for that must necessarily be liberated from both the zinc and copper acetates employed. The instructions, again, regarding the anodes, are indefinite as to their size, and the proportion of surface of each that should be relatively exposed for dissolution. By such a method, we therefore conclude that the deposition of brass must have been one more of luck than judgment.

A patent was taken out by Salzede, in which was recommended cyanide of potassium, sub-carbonate of potash, sulphate of zinc, and chloride of copper, nitrate of ammonia being subsequently added—a mixture in which the multiplicity of changes in composition that must be effected in forming the solution, indicates the inventor to have either forgotten the laws of chemical union, or to have had an imperfect acquaintance with them. Another liquid was also proposed by the same inventor, in which sub-carbonate of potash, sulphate of zinc, chloride of copper, and cyanide of potassium were employed.

Other patents were taken out for similar purposes, by which like solutions were employed, varied only in the proportion of ingredients. Potash and ammoniacal salts, the acetate and chloride of copper, sulphate of zinc, and cyanide of potassium, with a brass anode, being generally adopted; and a temperature varying from 75° to 100° Fah. was recommended.

By a specification of a patent taken out by Morris and Johnson, another, and apparently good, method of depositing brass was proposed. It will be seen that it varies really but slightly from the preceding in respect to the actual salts employed, but greatly as regards the mode of using them in making the solution; for the cyanides are made previous to, and not in, the solution.

According to this patent, dissolve one pound of cyanide of potassium, one pound of commercial carbonate of ammonia, two ounces of cyanide of copper, and one ounce of cyanide of zinc, in one gallon of water; and use the solution at 150° Fah., with a large anode of brass, and a powerful battery. Or a solution may be taken of one pound of cyanide of potassium, and one pound of carbonate of ammonia, dissolved in one gallon of water, and saturated with copper and zinc to the requisite degree by means of a strong battery, a large brass anode, and small cathode, until the latter receives a good deposit of brass; the solution being at a temperature of 150° Fah. To increase the proportion of copper in the deposit, either add cyanide of potassium, or raise the temperature of the liquid; and to increase the proportion of zinc in it, either add carbonate of ammonia, or lower the temperature.

It will be seen that the above is a much more scientific mode of procedure than those previously described; for by the first, or chemical process, no unnecessary saline or other substances are introduced; and, secondly, a simple mode of battery process for making the solution is also suggested.

Respecting this method, Mr. Gore observes—"Of the numerous solutions that have been tried for depositing brass, the one just mentioned is much the best. By it, reguline and thick deposits of brass, of uniform colour, and of any desired composition, may be obtained. It is not an expensive liquid; it acts with average strength upon the anode; it holds a sufficient quantity of the alloy in solution; it conducts electricity with moderate facility; and it yields its metal in the reguline state very uniformly; it bears a great variation in the electric power, without injury to the character of the deposit, and is, therefore, very easily managed; it does not act perceptibly upon cast-iron, wrought-iron, steel, or even zinc, so as to injure the adhesion of the deposit; and it is not decomposed by exposure to the atmosphere, to light or heat, in such a way as to affect its depositing power. Its defects are, that it requires to be worked hot, and with considerable battery power, in order to make the anode dissolve rapidly, the solution conduct copiously, and to cause a rapid deposit; it also evolves an abundance of gas at the cathode when working, whether the solution be hot or cold, which indicates that part of the battery power is ex-

pended in decomposing the water of the liquid, depositing its hydrogen with the metallic alloy, and oxidising the solution. But all the brassing solutions are, in a greater or less degree, imperfect."

This cannot be a matter of surprise when we consider the variety of affinities, electrical and chemical, that must be called into action in employing any alloy solution. We have, for example, the different affinities of cyanogen for zinc and copper, both in respect to dissolving the anode, and in regard to the constitution of the solutions of each cyanide. Then, again, there is the difference of the electrical states of the two anodes, if one each of zinc and copper be employed; and if, in place of that, one of brass be used, what standard of the composition of that alloy is to be adhered to? It is well known that "brass" is a generic term for a variety of zinc and copper compounds, varying greatly in the proportion of their ingredients; and we can only come to the conclusion, in reference to all alloy patents that we have yet seen, or processes recommended, that more is left to the intelligence and judgment of the electric current and chemical affinity, than to those of the operator; for he is compelled to leave them to select the exact proportions of each metal from the anodes, that he hopes to find deposited as brass on the cathode.

The deposition of alloys from alloy solutions is, indeed, a subject that will require the closest investigation of the scientific man for a satisfactory solution of its difficulties, rather than the empiricisms of those who, with a little knowledge of science, venture thereby to overcome them. In any other way, if success be obtained, it can only be chiefly ascribed to a fortuitous concourse of favourable circumstances that can only occur occasionally, and cannot, therefore, be relied on.

Various methods have been proposed for depositing German silver. Thus, by the battery process, the patentees last mentioned state, that by the following method the alloy can be successfully deposited:—"Dissolve one pound of cyanide of potassium, and one pound of carbonate of ammonia, in ten pounds of water. Immerse a large anode of German silver in the liquid, and a small anode of any suitable metal. Connect the two with a powerful battery, and pass the current until considerable metal is dissolved, and a bright cathode receives a deposit of a good colour, when the solution will be ready for use."

We have succeeded in depositing an alloy of the German silver kind, by using a mixed solution of the cyanides of copper and nickel with a German silver anode; but as the result obtained was more by accident than pre-arrangement in respect to preparing the solutions, we cannot say exactly the proportions of the ingredients employed. As near as memory now serves, the solution contained about an ounce each of the metals, a considerable proportion of cyanide of potassium (the latter being largely in excess), and a gallon of water. The liquid was worked at the ordinary temperature of the atmosphere; and two Bunsen's carbon batteries, exposing each twelve square inches of active surface, afforded the battery power. The receiving plate was about 12 × 8 inches in size; and the anode exposed about half that surface.

We have thus described the leading chemical, electrical, and other conditions of electro-metallurgy; the general laws of electro-chemical decomposition; sources of the electric current generally employed; moulds, depositing liquids, &c., &c.

From all that has been stated, it will be evident, that whilst, on an average, the art of electro-metallurgy may be carried on with a modicum of success, at least on the small scale, by a person of ordinary intelligence—if it be prosecuted largely as a commercial engagement or pursuit, a thorough knowledge of the principles and practice of the art will be absolutely essential.

It has been, therefore, our endeavour, in the preceding pages, to lay, as far as possible simultaneously, the science involved, and the application of it, before the reader. The mere teaching, separately, of abstract truth and practice, can never make any one proficient in any branch of science. Even in mathematics, the most abstract of all its branches, the beginner must combine, more or less, a knowledge of both. Geometry affords a remarkable example of an exceedingly simple subject becoming of the most abstruse character to the beginner, simply because all its reasoning is so purely abstract in its character. We, consequently, find that the simplest problem is with difficulty mastered by the beginner, until he can refer its solution to some practical purpose—a method of teaching, although objected to in some quarters, which has great advantages.

But in all branches of pure and applied experimental philosophy, the principles and practice should go hand-in-hand. It is all but useless to tell the student that, by the combination of A with B, a new compound will be produced; but if he is taught to produce that combination experimentally, he will at once see the results, and all the circumstances of its production. Each fact and principle will thus become apparent to, and fully appreciated by, the mind; and the information thus taught will not be easily forgotten, because abstract truth, and its practical application, have been simultaneously studied.

For this and many other reasons that we cannot here stop to detail, we strongly urge on our readers not to take for granted what has been advanced in the preceding pages, but to put all to the test of experiment. It is astonishing how much is thus learned. We could recount experiments that we tried hundreds, nay, perhaps, thousands of times in the laboratory and in public, that, old in themselves, almost always produce new features worthy of study and further investigation. We have previously noticed a remarkable instance of this in the common soap-bubble. Two hundred years

have elapsed since Newton first employed it to demonstrate his theory of the colour of bodies, and yet, so late as the year 1867, at the British Association meeting, Sir David Brewster, one of the most eminent investigators of optical science that have yet adorned the ranks of philosophy, proved, to the satisfaction of a host of leading philosophers present, that the cause of the colours of the bubble had till then been misunderstood. We may learn from such a fact a lesson of humility and perseverance—humility because of the little and imperfect knowledge we have; and perseverance so that we may successfully extend the boundaries of that knowledge.

The art of electrotyping is still very young; but having become highly profitable in practice, it has induced an astonishing amount of scientific and practical intelligence amongst those who follow it; hence the great extent of its application in the arts and manufactures. But the careful perusal of the preceding pages will show, that much as we have done, far more has yet to be acquired, both in principle and practice—a fact that will afford a stimulus to many who may propose to follow electro-metallurgy as a study or occupation.

Practical Details, Hints, Etc.

Besides the science and general practice of an art, there are involved in its pursuit numerous practical details, careful attention to which is necessary. Full acquaintance with them, and ability to put them into practice, are the tests of efficiency in the operator. Even in pure science the same constantly occurs. Some men are characterised by great ability in manipulation. Dr. Wollaston was, perhaps, a model in this way; and Faraday may be also cited as another instance of the kind. We believe that it may be justly said of Faraday, that he never failed in repeating an experiment at the lecture-table, forming a striking contrast to many whom we could, but will not, mention; who, by bungling, not only fail in the majority of experiments, but, on more than one occasion, have endangered the lives of the audience before them.

Let us first take a general glance at some of the details here referred to, before entering into more extended remarks.

The electro-plater generally receives articles for re-plating in a dirty state, or, more properly, in a condition utterly unfit for the operations that have to be performed on them. Such objects must, therefore, be prepared to receive a deposit. First being cleaned to remove dirt, oxide, &c., what silver is left on them has to be removed by an operation already alluded to, called "stripping;" for, if the silver remain on, and is electro-plated over, the surface would be irregular, and deficient in many requisites for a good appearance.

The cleaned surfaces must, in most cases, be still further prepared; for, without so doing, the silver would not adhere to them. Various causes (that will be afterwards described) render this necessary, and, generally, after the preceding operations. Objects of copper, German silver, &c., are coated with a thin film of mercury, which causes, all over the surface, the silver to be equally and closely deposited.

Some parts, as in gilding, it may be desired not to coat with gold; and these are, consequently, stopped off; that is, such surfaces are covered with a non-conducting material that prevents deposition. The choice of the substance so employed must be suited to the liquid used for depositing purposes; for whilst, in a sulphate of copper solution, a fatty matter might be safely employed, the same would be at once dissolved in a cyanide solution containing free or caustic potash.

In copying objects, again, the art of moulding is often one of great nicety and much importance. Of late years, engraved copper plates and wood-cuts have been enormously multiplied by the electrotype. As we have stated at a previous page, a good-hammered copper plate will not afford more than 700 or 800 impressions without requiring to be re-touched; an electro-copper plate will only yield 200 or 300; and a steel plate, perhaps 2,000. The engraved lines have then to be deepened, either by nitric acid or cutting with steel tools—a process that is just as long in execution as if the plate had to be in part re-engraved. But, at the present time, when any such plates leave the hands of the engraver, they are not, in many cases, printed from at all, except to obtain a few proofs. They are placed in the hands of the electro-metallurgist, who copies them, first, by moulding with some elastic substance: this is coated with a conducting film, and submitted to electro-copper deposition; by which an engraved plate, equal in all respects to the original—except, perhaps, in a few accidental defects that are soon remedied—is obtained. This, although exceedingly soft, may, by Joubert's acierage process, be coated with pure iron (see *ante*, p. 293); and then becomes even more valuable than a steel plate, to make which would have cost some hundred times the expense that is involved in electro-copper copying. It hence follows, that an original copper or steel plate may, without the slightest injury to itself, be copied to any desired extent.

Then, again, as regards wood-cuts, precisely the same process is adopted; and most valuable it is to those who publish illustrated periodicals, or other works. For example, the *Illustrated News* would require a vast number of wood-cuts, representing one picture, &c., so that as many printing-presses could work simultaneously in throwing off the week's impression. But the length of time required to cut so many by the engraver on wood, would be such as to entirely do away with the interest of the representation; for the value of the latter essentially depends on its being placed before the public at the earliest possible period after the occurrence of the event it is intended to illustrate. But the electro-metallurgist soon gets over the difficulty. The original is placed in his hands; he takes moulds from it, electro-coppers them, and,

in ten or twelve hours after he has received the original, he can supply as many exact copies as may be required.

The art is also applicable to a great variety of purposes, such as copying works of art of all kinds: for example, statuary, medals, old coins, &c. It is stated, that by means of the electrotype, the last application—that of copying valuable old pieces of money—is largely practised. A coin worth pounds may be thus multiplied at the cost of a penny. The necessary appearance of age is easily effected by chemical application, and, consequently, there are numerous collectors who boast of coins, &c., of the ancient Cæsars in their museums, the origin of which has been the neighbourhood of Clerkenwell or Birmingham. We need here hardly refer to another prostitution of the art in the electro-silvering of base coin, now so largely practised, and one that, in its pecuniary results, many of our readers may, most probably, have a "feeling" remembrance of.

Then, in the practical operations, are those of rendering non-conductible moulds conducting; regulation of the number, size, working, and general management of batteries, or the magneto-electric machine; the regulation of the quantity and quality of a deposit; its even spread on the surface of the object; choice of the best solutions for such purposes; attention to the temperature; polishing, burnishing, or deadening the surface; regulation of colour in gilded objects; and many other minor details that either have been dealt with, or yet remain to be noticed. The art itself is one of great delicacy, and requires a clear head, a sharp eye, and educated hands to carry on: it is, in fact, one that simply illustrates the saying, that what is worth doing at all is worth doing well.

In electro-metallurgy, as in all other industrial occupations, there are what are called "secrets of the trade." From a lengthened experience in all branches of manufacture, we have arrived at the undoubted conclusion that all such secrets are merely produced by a sharp and intelligent study of the circumstances of a process, and an equally intelligent application of the knowledge so obtained, in a manner greater in one person than another. In this we find the reason why some men succeed, whilst others completely fail in the same business. An instance that came under our notice some years ago may interest our readers, and, at the same time, be of value to those who are practically engaged in manufacturing operations. At that period a firm took a large government contract, but had hardly commenced its execution before, apparently, insuperable difficulties arose. The machinery they employed had been all newly made by one of the first engineers in Lancashire. At first it answered very well; but from some unexplained cause, the daily production gradually decreased, and, at last, almost ceased. This result became very serious, and threatened their ruin. In their extremity they called in the advice of a scientific person, also well versed in manufacturing operations. On inquiry, he found that the cause of their failure had primarily arisen from a change of dry to wet weather, that caused absorption of moisture on the covering of the rollers employed. He suggested a simple remedy, which, being applied, at once answered; and although its cost for the whole machinery was not twenty shillings, it increased the profit of the firm to the extent of upwards of twenty pounds daily.

Hence appears the necessity, especially in the art of electrotyping, of a careful study of all circumstances, and a ready and sagacious choice of remedies for difficulties as they arise. We now turn to consider such practical details as require constant attention in the carrying out of any branch of electro-deposition.

Preparing the Articles.—With the exception of silver, all the articles that usually are sent to the electro-metallurgist, for any purpose in which the objects are to be coated by silver or gold, are generally of the kind that are constantly subject to surface-deterioration by oxidation, and the general action of other agents present in the atmosphere. Questions of taste, health, &c., are involved in the requirements of the community; and, as a rule, an external coating of silver or gold—sometimes both—satisfies such, for they yield a surface that long resists the action to which we have just referred.

Of course, the value of such a deposit depends largely on the length of time that it resists removal; hence it is a matter of great importance to the electro-metallurgist, to make the coat that he deposits as adhesive as possible. If it break off from the surface of the base metal, his labour is not only lost, but his reputation is equally damaged.

Now, here it may be well to remark on the difficulty that exists in making two surfaces touch each other by any than purely chemical means. By the latter we attain the greatest possible contact between two bodies. Thus, if we place a piece of ordinary sheet zinc or iron in a mixture of water and sulphuric acid, the contact of the particles of all the bodies employed is so complete, that they all enter into fresh states or combinations;—the oxygen of the water unites with the iron or zinc, by which an oxide of either metal is formed; and this latter dissolves in the sulphuric acid, forming a sulphate of the metal employed.

Not so with electro-deposition under ordinary circumstances. For example, a copper plate left for twenty-four hours, after cleaning, in the open air, will have formed on its surface an exceedingly thin film of oxide, and also another plate composed of air. This is easily proved by a very simple experiment. Place a common sewing-needle carefully on the surface of cold water: it will be seen that the needle, although seven times heavier than its bulk of water, will actually swim on the surface of the liquid. But if the needle be first heated in the flame of a candle, &c., it will, on being placed on the surface of water, at once sink to the bottom of the vessel holding the liquid. The reason of this is, that a thin film of air that encircled the cold needle is removed by heating the needle; and, consequently, that which previously sus-

tained the needle in a swimming position has been removed.

Now, precisely the same circumstances occur in reference to most metals that are submitted to electro-plating and electro-gilding operations, and even, as we shall subsequently show, in respect to the deposition of copper, &c. They have on their surface a film of oxide, air, and, frequently, "dirt," vulgarly so called, that would prevent the adhesion of the coating intended to be communicated to them.

Hence the following means have been proposed to obviate the difficulties above alluded to, and others that arise in practice.

Generally it may be supposed that fatty matters are present on most objects sent to the electro-plater; for in all domestic operations, "grease" is by no means the least common of deteriorating influences. Caustic alkalies are the only reliable means of removing such obstructions to the operations of the electro-metallurgist. A solution of common soda, rendered caustic by the addition of newly-slaked lime, is an excellent detergent of all such fatty matters. The latter are about the worst conductors of electricity that the practical man can meet with.

Presuming that the fatty matters have thus been removed, the next step is to take off the oxide from the surface. The mode of doing this must depend on the metal that has to be dealt with. "Articles formed of zinc, wrought-iron, cast-iron, or steel, are first immersed for a few minutes in a boiling solution of caustic potash, to remove any grease, tar, or oily substance that may be upon them; they are then washed in water; and those of wrought or cast-iron are immersed in 'pickling liquid' [dilute sulphuric acid] until the acid acts rather freely upon them. Rough cast-iron requires a stronger liquid than smooth wrought-iron. After being again washed in water, they undergo the operation of the scratch-brush, described at p. 283, *ante*. If they are very coarse, they may require several soakings in the dilute acid, and scouring with sand and a hard brush, and even filing, to make them quite clean."

The latter process certainly can only be prudently carried on in respect to remarkably rough subjects, and its adoption must, consequently, be left to the judgment of the operator. All we can add is simply the advice, that any of the objects precedingly named, should be freed, as far as possible, from anything that could possibly hinder a deposit being made thereon. As already noticed at a previous page, all copper articles, or those containing copper as an alloy, must be dealt with differently. Copper being insoluble in sulphuric acid, nitric acid, in its dilute condition, commonly known as *aquafortis*, must be used.

"Sometimes, in order to assist in clearing the articles, they are suspended for a short time in the depositing liquid, in contact with the negative pole [the anode] of the battery; this dissolves the surface, and loosens the impurities, unless the surface be very foul, or the solution is too valuable [to make the process economical]. In every case the articles should be well rinsed with water, to remove any adhering acid, before dipping them into a mercury solution, or immersing them in the depositing-trough. All objects that are to have a definite weight of metal deposited on them, must be weighed, and their weight noted down after they have been cleaned."

The last paragraph of the preceding quotation indicates, as we have already often noticed, the precision of operation that attends the processes of electro-metallurgy. Of course, the extra deposition of a few ounces of copper is a question of trifling importance; but when silver or gold is deposited, the matter becomes one of great consideration; and, indeed, involves the very existence, as a commercial man, of the person engaged in such operations.

Mr. Gore gives the following directions for preparing articles for adhesive deposits; that is, those on which silver or gold are to be deposited for surface purposes by way of ornamentation, &c.:—

"All articles intended for the depositing-vat should be cleaned in the most perfect manner possible before being immersed in the depositing liquid, otherwise the deposit will not adhere. Articles of copper, brass, or German silver, which are to be silver-plated, should also be dipped into one of the solutions of mercury [named at p. 285, *ante*], otherwise the deposit will not adhere at all, or will vary in appearance in different parts; and in consequence of this perfect degree of cleanliness required, the cleaning of them involves more trouble than the depositing. All articles should be plunged, while still wet [from clean water] from the cleaning process, into the depositing-vat. The practical *minutiæ* of preparing the surfaces of different metals for receiving adhesive deposits of other metals, vary in almost every manufactory."

General rules, however, may be safely laid down, as already noticed. It has been previously stated, that absolute contact between two bodies, other than by chemical attraction, is barely possible. It hence follows, that chemical attraction, or affinity, should, in all possible cases, be taken advantage of.

Whatever method is employed to render non-conductible surfaces conductors, it need scarcely be remarked that the utmost care should be observed in making the conducting surface continuous. Already we have noticed several methods that have been proposed—such as black-leading, the covering of surfaces with silver, &c.; and to which we may add, the application of a thin film of gold, silver, copper, or zinc leaves to a non-conducting surface. The art of black-leading—that is, applying a conductive surface of carbon to a non-conductible object—whilst extremely simple in description, requires certain precautions. The following advice is of value: —"Apply the black-lead by means of a soft camel's-hair brush with a large and thick body of short hairs, breathing upon the face of the mould occasionally, to facilitate the adhesion of the material. When the object is perfectly black and bright, blow off the superfluous black-

lead. The mould is then ready for receiving a deposit. The whole operation need only occupy about ten or fifteen minutes, if a small object, for the first time in preparing it; and still less in subsequent operations.

"If the mould be very large, and especially if it have deep hollows in its surface, it will require, after being black-leaded, to have several short and fine copper 'guiding-wires' carefully attached to the main wire [that is, the wire leading from the zinc of the battery]; and then free ends slightly inserted in the face of the mould, in the most hollow and distant parts, or to lie in contact with them, in order to cause the deposit to commence and spread there as well as round the edge. If this precaution be not taken, the deposit will be much thinner over those parts [the most distant from the conducting wire of the battery], than upon the nearer and more prominent places; and, sometimes, will not spread over them at all."

The advice above given, whilst of great value, may be modified considerably in its practical adaptation. If black-leading be carefully done, the deposit, unless the surface be very large, rapidly spreads on a mould—at least, so we have found it in practice.

In respect to the regulation of the quantity and intensity of the electric current—whether derived from the voltaic battery or the magneto-electric machine—much has already been said. It is a matter of the highest importance that these points should be carefully considered, for on them entirely depends the success of the entire art of the electro-metallurgist. We have seen that, if the *intensity* be too great—that is, if the number of cells be extended beyond the right proportion to the strength of the solution employed—gas will be disengaged at the cathode, and the metal will be deposited in a rotten condition, utterly worthless for all ordinary purposes; and, equally, if the *quantitative* power of the battery be wrongly regulated, the quality of the metal deposited will also be affected.

In respect to quantity, if a voltaic battery be the source of power, a very convenient method is to employ large plates, the depth of immersion of which in the liquid exciting the current will regulate the quantity of electricity afforded; and by such means a gradation of depositing power may be at all times ensured. Thus, by using a battery of one cell—say, of 200 square inches of surface—by merely lowering the plates to the extent of half their depth in the gas (presuming that Smee's arrangement is employed), only half the power of the cell is called into action. An extra inch, or any further immersion, can thus be made; and, consequently, the question of quantity is entirely under control. Similarly, as we have already shown at p. 276, *ante*, by increasing the charge of acid, the quantity, up to a certain extent, may also be increased. Again, if the plates of the battery cell, or the electrodes in the depositing-vats or trough, be approximated, or removed further from each other, so the quantity of the current may be increased or decreased to any desirable extent. The length of the conducting wires from the battery to the depositing-trough, may also be used as a means of regulating the quantity and intensity of the current employed; and, similarly, the interposition of liquid, in place of solid conductors, may, for reasons explained at p. 276, *ante*, be used to regulate the effective force of an electric current, no matter how that has been generated.

Although repeated description has been given of the methods that may be adopted in regulating the quantity and intensity of a voltaic battery, it may not be without advantage if we illustrate the arrangements that may be made for such purposes. In the following cuts it is supposed that Smee's batteries are employed; but the remarks and illustrations equally apply to any other form of battery.

Fig. 180, represents a battery of four cells, arranged in what is generally termed "single series;" that is, by employing *four* cells, arranged so that the platinised silver of one is connected with the zinc of the next, *four* times the intensity of one cell is obtained by the arrangement.

In Fig. 181, an entirely different arrangement is adopted. All the zincs and all the silvers

Fig. 181.

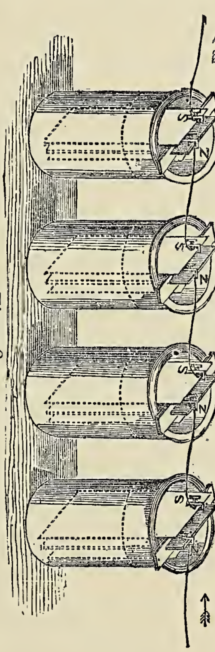
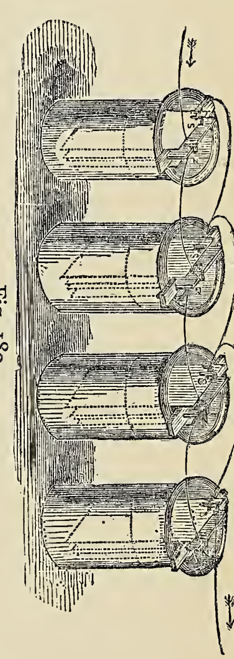


Fig. 180.



are respectively connected together, affording *four* times the *quantity* of a single cell, with the *intensity* of *one* cell only.

Again, in the following illustration, the connections are so arranged that four cells afford the quantity of two, and the intensity of two; that is, the zincs and silvers, respectively, are connected by wires in such a manner, that the *intensity* of four cells is *halved*, and the quantity of *one* cell *doubled*; that is, two zincs are joined together, as are two silvers; hence the four

pairs afford a battery of two cells, each pair having double the size of negative surface of a single pair.

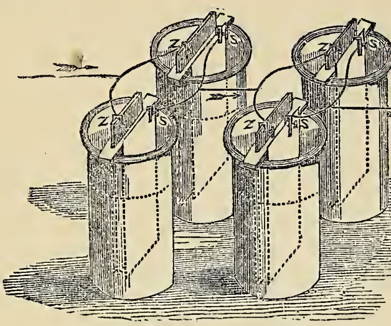


Fig. 182.

It hence follows, that if, for the sake of convenience, the electro-metallurgist has furnished himself with a battery of any sized plates, he may convert number into quantity or intensity power, just as he pleases. Nay, still further, as the quantity afforded by any cell is regulated by the distance that the zinc plates (in a Smee's battery) are from the platinised silver, the quantity may be increased by diminishing that distance, until the plates are but the slightest fraction of an inch apart.

Dependent on the *quantity* of the battery power employed, is *that of the metal deposited.* On this subject we have already made extended remarks at p. 280, *ante*—a reference to which will place the reader in possession of the main facts of the question. A common rule to abide by is, that the amount of zinc dissolved in *each* cell is a measure of the quantity of metal deposited on the articles of the receiving vat. As already shown, if two cells be employed, double of the zinc in equivalent measures must be used to deposit one equivalent of the metal received at the cathode, whether they are articles in process of coating with copper, silver, gold, &c. But this rule only applies when the purest zinc is employed as the positive plate of the battery. This never occurs in practice, simply because the best amalgamated sheet zinc is replete with impurities that cause its waste; consequently, the real amount of zinc dissolved in practice, will far exceed that which, theoretically, should be consumed.

These remarks may be still further impressed on the mind of the reader by a quotation from an author to whom we have been already much indebted. He says—"The quantity of metal dissolved and deposited in the vat, is in direct proportion to the quantity of zinc dissolved, and acid consumed in each alternation [that is, any number of cells] of the battery; with a perfect depositing liquid, good battery arrangements, and pure materials, for every equivalent of zinc dissolved in each alternation [cell] of the battery." This has been already explained at p. 267, *ante*, when we treated on electro-chemical equivalents, as being identical with those of purely chemical affinity value. But, from a variety of causes, such as impurity of materials, practical mistakes—that is, difference between theory and practice in working—a loss of 25 per cent. should be considered as an average charge of the expenses of the electro-metallurgist, beyond the cost of depositing, &c., that theory would point out.

At first sight, this would seem at variance with what we have previously stated to be a characteristic of electro-metallurgy; that is, the *exactness* that should characterise its operations. But it must be remembered, that in making statements bearing on such matters, we presumed that every material employed was, under such circumstances, supposed to be absolutely pure. Practically this never occurs; and yet that circumstance need cause no inconvenience. At p. 271, *ante*, and subsequent pages, we have pointed out how the electro-metallurgist can, by chemical analysis, at all times control the question of purity of the articles he employs; and, such being the case, it requires no argument to vindicate our first position—that the art of electro-metallurgy stands foremost in the exactness of its details, simply because the operator is at all times in possession of very simple, but certain, means of testing the chemical, and, consequently, the commercial, value of the articles he purchases.

In respect to the regulation of the quality of the deposit, much has already been said. At p. 266, *ante*, some general laws have been laid down that regulate such results, and they are invariable in their application. Mr. Gore's remarks on this question may be quoted as still further elucidating the subject:—"The quality of the deposited metal—that is, its degree of cohesion, hardness, flexibility, &c.—depends on the intensity of the current. As a general rule, the greater the intensity, and the smaller the quantity of the current, the harder and brighter is the deposited metal; and the greater the quantity and the smaller the intensity, the less coherent and softer is the deposit. To obtain a very hard, bright, and crystalline deposit, we should use a current of small quantity and high intensity; and to attain a soft black-powder deposit, we should employ large quantity and low intensity. The combination of moderate quantity and moderate intensity produces a coherent reguline deposit, possessing all the ordinary characteristics of the particular metal. These results can only be obtained with a good depositing liquid, and with metals such as copper, silver, gold, &c., which are known to exist in a complete reguline state; and not with those—such as bismuth or antimony—crystalline metals which do not exist in that state. * * * If we are producing a reguline deposit with a one-cell arrangement in a good depositing liquid, with electrodes of the same size as the immersed portion of the battery plates [in their exciting cells], and it is wished to change the deposit to a soft black powder, the plates of the battery must be immersed considerably deeper in their exciting liquid [that is, the quantity of the current must be increased], and a very much larger dissolving plate [or anode] in the depositing vat

must be used. If we wish to change the deposit to a crystalline one, several more cells, or pairs of the battery, must be put on, connected intensity-fashion [as shown at p. 325, *ante*, Fig. 180], and the plates must be immersed to an exceedingly small depth in their liquids, and a very small anode employed. These results have also a direct reference to the size of the receiving surface; for if, with any given battery and anode, we are producing a black-powder deposit upon a very small article, a larger one would receive a reguline deposit, and a much larger one would have thrown down upon it a deposit bordering upon the crystalline state. Thus it will be perceived that the black-powder deposit is the result of a too rapid, and the crystalline one of a too slow, action." For such reasons, as already noticed, at a high temperature, and with a strong solution and powerful battery, gold may be precipitated almost black in appearance; whilst copper, by a cold solution and a weak battery, may be obtained in crystals; although, as we have seen, most metals may be, by proper precautions being attended to, procured readily in the most perfect reguline condition.

In respect to the spread of the deposit, the same authority remarks—"If we wish to make a deposit spread rapidly over a metal of inferior conductibility, such as a long iron rod, we must use a current of high intensity and rather small quantity; this will drive it over the surface without causing it to become soft or non-coherent. The action of such a current appears to consist in conferring upon the particles a kind of polarity, a power of grouping themselves into separate warty nodules or crystals, each of which, as it becomes larger, appears to powerfully repel its neighbour, and thus causes the metal to spread rapidly. When this action is continued to a considerable thickness of deposit, especially in cold weather, the metal is exceedingly hard, and easily broken into a number of distinct grains or nodules, which are in the form of warty lumps with rounded edges. If the action have been rather too quick, or the liquid not sufficiently cold, and the deposits be composed of more or less perfect crystals, with edges sometimes beautifully defined, or when the action has been very slow, and the liquid very cold and undisturbed, the same occurs. With the intensity of one hundred pairs of Smee's battery, acting for a long period of time in cold weather, and the quantity of the current kept down to the lowest possible degree, we have seen a tough deposit of zinc spread over several square inches of clean gutta-percha; and in depositing copper with a current of rather high intensity, and small quantity, upon black-leaded gutta-percha medallions, we have repeatedly observed, that where there was a sunk boundary line near the edge, the deposit remained quite thin, as if powerfully repelled, whilst on each side of the line it was very thick, and on the outside edge, accumulated in large warty masses, hard and distinctly separate, and containing as much metal as the whole of the medallion besides."

It may be thus noticed, that the variety of conditions that lead to a perfect reguline deposit is great, although the conditions absolute to the production of that result are few in number, and at all times perfectly under control. Hence the following instructions in reference to the management of all working solutions are of high value:—"In working any depositing liquid —1st. Avoid doing anything which might alter the chemical composition of the liquid, or even the proportion of its ingredients, except water, which may be altered in proportion, in most depositing liquids, without much inconvenience. 2ndly. Adapt your electric power to the liquid, rather than the liquid to the power; and regulate the deposit rather by alterations in the battery than by alterations in the depositing vessel, except as regards the distance of the electrodes, or the temperature of the liquid. These may be altered with safety, and sometimes with convenience. 3rdly. As a general rule, let your dissolving metal, or anode, expose a larger immersed surface than the receiving article, or cathode."

It has already been pointed out that the position of the electrodes in the vat is one of much importance, and, equally so, is their distance; because the further they are apart, the greater is the resistance to the passage of the current, and, consequently, of the active quantity of the current. Theoretically, the anode and cathode should be as close together as possible short of absolute metallic contact; but, practically, this is impossible; for, if such a plan were carried out, the proper circulation of fresh liquid between the two electrodes would be unattainable. In a single fluid battery, such as Smee's, the closest approximation of the positive and negative plates is attended, in exact proportion of proximity, with an increase of quantity. But in cases of secondary action, which constitute the majority of electro-metallurgical operations, a certain interval must be left between the anode and cathode, so that sufficient of the depositing liquid shall be present to effect all changes of chemical and electro-chemical affinity that arise, and are required to be brought about.

This matter has incidentally been already dealt with at pp. 298 and 299, *ante*, when we entered into the question of the constitution of a silvering solution, and the mechanical conditions that must be attended to, for the purpose of obtaining successful results: but there are certain general rules in respect to the position of the receiving articles and dissolving plates, that must be observed; and, respecting them, the following remarks by Mr. Gore are well worthy of attentive perusal:—

"The best practical position for the dissolving plate is the vertical, the dissolving plate and the receiving article being suspended in the liquid facing each other, the latter being rather the lowest of the two, and both wholly immersed. The horizontal position, with the dissolving metal above, although the most philosophical arrangement, does not succeed in practical working; because the metal used for dissolving is never quite pure (with copper es-

pecially), and the impurities from it fall upon the surface of the receiving article beneath, and make it rough : in addition to this, the position of the article prevents our being able to examine it easily, or remove it conveniently. If the article to be coated have a very irregular outline, either the dissolving plate should be bent somewhat to its form, so that the two may be nearly equi-distant at all parts ; or the article should be often shifted in its position, so as to produce a nearly uniform thickness of deposit all over. The nearer the receiving article is to the dissolving plate, the more rapid is the deposit ; and a large body of liquid deposits more rapidly, and more evenly, than a small one ; large connecting wires are more favourable to quick deposits than small ones. The greatest thickness of deposit always takes place upon the most prominent places—*i.e.*, upon those parts nearest the dissolving metal."

The numerous applications to which electrotyping is now devoted, would render it necessary, if we could enter into all the details, to occupy an amount of space incompatible with the limited size of this work ; and not only so, we should be compelled to weary the reader with a multiplicity of directions, and *minutiæ* of description, only applicable in special cases, and, therefore, not of general interest. All the most important subjects have been already fully dealt with, and many of minor character we must necessarily leave untouched.

Some large publishing firms have substituted, in part, the copying of set-up type by electrodeposition in place of the more general method of stereotyping. By the latter method, a copy is made in type-metal, through first obtaining a mould, made of paper, from each page or forme ; and this mould being fixed in a suitable frame, an alloy of antimony and lead is poured in : the mass, on cooling, affords, of course, an exact copy of the original page of type.

"The plan adopted is similar to that of copying wood-cuts [see *ante*, p. 322]—namely, to lay a sheet of softened gutta-percha upon the surface of the page of type, and subject it to increasing pressure until it is cold. The gutta-percha copy is then removed, and treated as in copying wood-engravings." On this subject Mr. Gore remarks—"It would be advisable to try a somewhat softer material for this purpose, such as the mixture of gutta-percha and marine glue [already described at p. 287, *ante*]. This material takes a sharper and smoother impression than gutta-percha alone, and the deposit spreads over it more rapidly. Being softer, it enters more freely, and with less pressure, between the finer lines of the letters ; and still is not sufficiently soft to penetrate the minute crevices between the body of the types. If a solution of grape sugar (as used in Drayton's patent process for silvering glass), aldehyde, or other reducing agent, were substituted for the phosphorus solution for reducing the silver upon the surface of the mould, it would be an advantage; as, besides the dangerous character of the phosphorus, it has an offensive odour, and the copper deposited upon surfaces prepared by it, moreover, is invariably brittle. The mould may also be prepared for a deposit by black-leading : it will require a first-rate quality of black-lead, and prolonged and attentive brushing ; but will then afford a good result. The air-bubbles may be removed when the mould is in the liquid, by directing a powerful upward current of the liquid against them by means of a vulcanised india-rubber ball or bladder, with a long and curved glass tube attached to it [as shown in the following cut] ; but the liquid should be free from sediment.

Fig. 183.

"The advantages of electrotyping over stereotyping are numerous : the metal is harder, takes a sharper impression of the mould, and delivers the ink much more readily than type-metal, besides being a cleaner process. It also takes up less ink ; and, consequently, the printed pages dry more quickly."

It is perfectly evident that, by reversing the position of a plate to be engraved—that is, by making it an anode in place of a cathode in a copper solution—it may be effectually etched ; and the method becomes a substitute for the usual mode of employing nitric acid for that purpose. For example, a copper plate carefully planished, polished, &c., as ordinarily prepared for the copper-plate engraver, is covered with the usual etching-ground—a species of varnish. The design is drawn through this by a steel etching-tool, so as to expose the subjacent copper surface in which the lines have to be etched to form the printing-surface of the plate. Now, by the ordinary process, nitric acid, diluted with water, is placed on the surface of such a prepared plate ; and the acid gradually "eats away," or dissolves, the copper so exposed, forming lines cut into the plate, that afterwards receive the ink of the printer. But if, instead of using the acid, a plate so prepared be suspended by a wire in the ordinary copper depositing liquid, and made the anode of a single cell, whilst the zinc of the latter is attached to a similar-sized plate, to form the cathode in the depositing solution, the copper on the engraved plate will be dissolved away at all those portions unprotected by the etching-ground ; and, consequently, the etching of the plate may be readily effected. The amount of this action on any particular part of the plate may be regulated to any desired extent, by approximating the cathode thereto, for the purpose of deeply etching the plate; or if deep in-cut lines be not required, as in the lighter part of the intended engraving, then the action is lessened by removing the cathode further from such parts.

Despite the advantages thus offered by this mode of etching, we believe that it is rarely employed. The engraver, by practice, can so regulate the action of acid in the usual mode of etching, that but little, if any, uncertainty attends the operation ; and, not only so, he has

the plate constantly under his eye, and can watch it at every moment; which is, of course, impossible if the electro-etching process is carried out. When the art of the electrotype first became popular, many adaptations of it to engraving purposes were suggested and patented; but, at present, the "steeling" of copper plate surfaces by Joubert's process, and the copying of them by gutta-percha moulds (as already described in detail in the preceding pages), are almost the only purposes to which the engraver applies them.

Glypography was one of these early applications. "This art consists in varnishing the back of a flat and smooth copper plate, laying first a thin coating of white etching-ground upon its front side, and then a layer of black etching-ground upon that; engraving the design upon the coating with different tools; then black-leading the whole engraved surface, and depositing a thick sheet of copper upon it in a sulphate solution by the battery process, in the usual manner. The deposited plate is then removed, its defects corrected, and it is fixed on a block of wood, in the same manner as an ordinary stereotype plate, ready for printing from at the ordinary hand-press." This method, in careful hands, produces very good results; but its application has been very limited in practice.

An outline of the method of etching Daguerreotypes, and of M. Pretsch's process of engraving by light and electricity, has been given at p. 281, *ante*, to which we must refer our readers. The operations there described are exceedingly interesting, as connecting the two forces of light and electricity for the production of engraved surfaces; but, as there stated, practical difficulties have prevented any extended application of either of the processes for engraving purposes.

The method of taking copies of busts, so far as the art of moulding is concerned, has been mentioned at p. 288, *ante*. It is one that is not much employed, but is very valuable for some purposes, especially when the number of copies required is limited, whilst precision of outline is desirable. Of course, the usual method of casting is more eligible, whether in respect to cost or time.

A very pleasing and ornamental application of electro-metallurgy is found in copying objects in nature, such as leaves, fruit, &c. We have seen some beautiful specimens of this kind, that were so exact as to reproduce the most minute features of interest in the object. Leaves and their twigs are easily so coated with copper. They may first be dipped into melted white wax, so as to form a very thin coat on their surface. This will give them, when cool, sufficient strength to be stiff; and also a surface that can be prepared for conduction. The latter operation is effected by rubbing the whole surface with black-lead, by means of a soft brush. The stem is then attached to a copper wire, and black-lead is again applied at the junction, so as to make the conducting surface continuous between the object and the wire. The article so prepared is made a cathode in the usual sulphate of copper depositing solution. It will gradually be coated; and when a sufficiently thick film has been deposited, the article may be removed, and well washed. It may be retained in the copper state, or painted the colour that the original leaf possessed. But a very pleasing result is attained by plating and gilding such objects by the means already fully described. They then become elegant articles of ornament; and the taste of our readers will at once suggest numerous applications of that kind which may be made.

Another pleasing and ornamental application of electro-coppering is that of coating lace, &c., with copper, and, subsequently, of silvering or gilding them. We have seen some beautiful bracelets and other forms of jewelry thus made. Lace, for example, is dipped into melted white wax; and, whilst cooling, it may be bent into any desired form, which, of course, it will retain when cold. The surface is then well black-leaded, and electro-coppered in the usual way.

In copying fruit, various methods may be adopted. The object—say an orange or apple—may be coated with a thin film of white wax, and black-leaded, by which the exterior surface will, of course, in the subsequent operation of electrotyping, be covered with copper, that may afterwards be plated, gilded, or otherwise dealt with according to the taste of the operator. The juices will gradually evaporate if a few fine holes be drilled into the copper surface. Another method is to take a copy of the fruit by the usual method of wax-moulding. Of course, the mould must be taken in two halves, the interior of which is then black-leaded, and, subsequently, coated in copper by the usual battery process. Of course two halves are thus obtained, which can easily be soldered together. By a little ingenuity some objects may be coated to form one copper copy: after black-leading the wax moulds, they may be joined together. A hole must then be made at one end large enough to admit a copper anode; whilst the mould itself is attached as a cathode to the zinc of the battery. A sulphate of copper solution is then poured into the mould, and gradually the interior will become coated with copper over its whole surface. When the operation is complete, the solution is to be poured out, the moulds removed, and the copper copy will be found complete, except that possibly a projecting mark may occur at the junction of the two moulds; but this may easily be removed by gentle filing.

We have not made any remarks on the methods of polishing, and otherwise finishing off the exterior of electro-metallurgical objects. The practical man needs no advice in this matter; and the amateur may easily adopt any of the ordinary methods of applying polishing powder, &c., &c. On electro-silvered and gilded articles, an alternation of dead and polished surfaces looks exceedingly effective. The dead appearance, as already shown, may be produced by managing the solutions in respect to strength, temperature, and other conditions. It has also been explained how, by the use of bright *silver* solution, that metal may be deposited in both a polished and

dead state. The polish, however, requires to be improved by aid of the burnisher; which, whilst giving a highly reflective surface, at the same time communicates a kind of black, or exceedingly full, reflection from the surface of the article.

In respect to the ornamentation of copper articles, the following hints may be of service to many of our readers :—

"It is usual to give medals and ornamental objects a coating of bronze, that they may acquire a permanently agreeable appearance. This is effected in various ways : the bronzing may be brown, black, or green ; and the selection of the method adopted is entirely a matter of taste. To avoid sameness of appearance in a cabinet, the amateur is recommended not to confine himself to one method ; and therefore we shall here give brief directions for imparting a permanent tint of each of the three colours mentioned.

"A very good *brown* bronze is obtained by adding to a wine-glass of water, four or five drops of nitric acid. The medal is first to be carefully cleaned from oil or grease ; and is then to be wetted with this solution, and allowed to dry. When dry, it is exposed to a gradual and equable heat, and the bronzing, or darkening of the surface, will proceed in proportion to the heat applied.

"Another very beautiful brown bronze is obtained by the simple application of plumbago, or black-lead. The medal, being previously cleaned from wax or grease by washing it in a little caustic alkali, is brushed over with black-lead, and is then placed in an oven, or laid on an iron plate over a clear fire, until it is too hot to be touched. In this state, a few strokes of a plate-brush will produce a dark-brown polish, approaching black, but entirely distinct from the appearance of black-lead. If the medal has been kept for some days, or carefully polished, the same operation will impart to it a rich, brilliant, and agreeable colour, between red and brown.

"A dark-coloured bronze is obtained by dipping the medals into weak acid solutions of platinum, gold, antimony, &c., and then washing and brushing them. If a darker colour, approaching black, is required, the medal is washed with dilute sulphide of ammonium, and dried at a gentle heat. It is then polished (but care must be taken not to scratch) with a hard hair-brush. Any sulphuretted alkali may be used, although the ammonia is preferred.

"To communicate a green bronze is an equally simple operation, but requires a little longer time. For this purpose, the medal has only to be steeped for some days in a strong solution of common salt, or of sal-ammoniac ; it is then washed in water, and allowed to dry slowly. Immersion in a strong solution of sugar, or exposure to the fumes of dilute acetic, or to weak fumes of hydrochloric acid, and to several other vapours, will answer the same purpose. The solution of sugar is improved in effect by the addition of a little acetic or oxalic acid. A fine *antique* green bronzing is obtained by suspending the medal in a dry covered vessel, in the bottom of which has been placed a little bleaching-powder. A few grains of the powder are sufficient, and the depth of the coating may be regulated by the time of exposure. The tints also may be varied, according as the medal is clean or tarnished, dry or wet, when suspended."

The latter method is frequently adopted to give the productions of modern art the appearance of age. We have already mentioned how collectors of old coins, medals, &c., may be thus "taken in." In fact, the perfection of the art of copying in metal afforded by electrotyping processes, and the various aids that chemistry supplies, enable us to obtain exact fac-similes of almost any object, old or new, and which may thus be produced with a perfection which will defy distinction from the original, except by the practised eye. In many other branches of trade than those already mentioned, this is largely taken advantage of.

CHAPTER XII.

MAGNETISM.

At an early period of the history of magnetism, the force, power, or whatever we may call it, seemed isolated from all others. It was considered as *per se*. The ancient writers that can be depended on—such as Homer, Pythagoras, and Aristotle—referred to it, ignorant, of course, of its nature ; but, at the same time, aware of many of the facts that accompany its phenomena. Sir David Brewster remarks—"From references made to the magnet by Euripides, Claudian, and others, and from the experiment with the rings mentioned by Pliny, it is not very improbable that the ancients were acquainted with the communicability of magnetism to iron bodies. The magnetic properties of the loadstone, like the electric of amber, were supposed to be miraculous. Medical qualities of various kinds were ascribed to it ; and even Hippocrates ranked it amongst the number of purgatives."

But we need not go far back to find erroneous opinions in respect to magnetism. In our own day, theories have been brought forward by no means creditable to the sagacity of humanity.

At every period of the history of mankind, it is but mild to say that the most erroneous conclusions have been adopted in respect to the explication of natural phenomena. Men constantly measure their mental strength with their great Master; and, unless exceedingly cautious in the proposition of theory, have heavy falls. Even at the present day, with all the experimental knowledge that we may justly boast of, it becomes constantly apparent, that we must unlearn that which we have implicitly believed; disbelieve that which has been pertinaciously taught as truth; and simply confess that we are ignorant of that which, in the conceit of our "intellectual" discoveries, we have imagined ourselves to have completely understood.

The very tyro in science cannot but regret the obstinate adherence to theoretical views that frequently characterises the "man of science." For our own part, acquainted personally with Barlow, Sturgeon, Snow Harris, Faraday, and other eminent electricians and magneticians, we can only approach the subject of *Magnetism* with fear and trembling. Electricity—its sister science—has become far better developed. There is much more precision in the experimental investigation of electrical phenomena, than can be arrived at in respect to similar investigations of such as are exhibited by magnetism. The latter force is restricted in its manifestations, simply because the instruments we employ only in part exhibit *signs* of the phenomena that result from the action of the force. And not only so, we are compelled, to a large extent, to hypothesise on that which, philosophically, before we proceed to induction, we ought to know. For example, we assume the sun to have a magnetic power, yet we have no proof of it—we simply guess that such may be the case, because, at certain hours of the day, we find that magnetic phenomena are more intense than at other periods of the twenty-four hours, or nearly so, of the sidereal rotation of our earth. But, on the other hand, we find an apparently connected variation of the barometer, periodic in its character, and evidently intimating that some relation must subsist between gravitation, magnetism, atmospheric pressure, and many other phenomena of nature.

These remarks are intended simply to fence ourselves from being committed to any theory that may be propounded in the following pages. Our earlier scientific education was commenced by a study of Bacon's *Organon*, and Newton's *Principia*, continued by a careful study of the writings of Faraday, and, still better, his personal advice and direction in many matters. Hence, bred in a school of experimental philosophy, we rather relate, in many cases, the views of our present philosophical teachers than believe in them.

Sir David Brewster, in his *Treatise on Magnetism*, in the *Encyclopædia Britannica*, thus categorically states the general phenomena of magnetism—"A body is said to be magnetic when it has the power of attracting soft iron-filings, or [the same metal] in large portions; or of attracting and repelling other magnetic bodies like itself; of taking a particular position when freely suspended or moving on a pivot; and of communicating magnetism, either temporarily to soft, or permanently to hard iron, in the form of steel. Hence we may arrange the several properties of magnetic bodies under the following heads:—

"1. On the attractive power of magnetic bodies on soft iron.

"2. On the attractive and repulsive power of magnets on each other, or over iron, either temporarily or permanently magnetised.

"3. On the effect of masses of iron on the attractive force of a magnet.

"4. On the polarity of magnetic bodies.

"5. On the power of magnets to communicate magnetism to the bodies.

"6. On the distribution of magnetism in artificial magnets.

"7. On the effect of division and fracture on the distribution of magnetism.

"8. On magnetic figures."

We have copied the above from Sir David Brewster's *Treatise*, simply because it shows what may be properly termed a *résumé* of pure magnetism; but, at the present day, magnetic phenomena cannot be disassociated from those of an electrical character. It is scarcely less than conclusively shown that electricity and magnetism are practically convertible terms for the expression of the effects of their combined phenomena, and hence it is barely possible to deal with them separately. An analogous case arises in chemistry. In our younger days the science was divided into *Inorganic* and *Organic* chemistry; but gradually it became evident that no such distinction could properly be maintained, simply because the same elements, hydrogen, oxygen, carbon, and nitrogen, are equally constituents of the animal, vegetable, and mineral kingdoms. For such, or rather analogous reasons, we must, to a certain extent, include the consideration of electrical phenomena with those of magnetism. Hence the origin of the branches of science denominated *Electro-magnetism*, *Dia-magnetism*, and allied matters, to be hereafter more particularly detailed.

We commence by describing such of the phenomena of magnetism as are most popularly known, so that we may proceed from familiar subjects to those of a more abstruse nature.

MAGNETIC ATTRACTION AND REPULSION, ETC.

The earliest form in which the properties of magnetism were known, consisted in the attractive power of the loadstone. These properties have been known for ages; for ancient writers, such as Pythagoras, Pliny, and others, intimate the knowledge possessed by the ancients. It is an oxide of iron, and forms a very valuable ore of that metal. It occurs in almost every part of the world. The form called *Magnetite* by mineralogists, is that which

is the most highly magnetic. According to Professor Tennant, Siberia and the Hartz mountains produce the most powerful natural magnets, or loadstones. Brewster describes it as an ore of iron, of a gray colour, and a dark metallic streak, with a specific gravity of four and a-half times that of water; of a crystal form of the regular octahedron. Specimens may be generally obtained of any philosophical instrument-maker, by those desirous of making a personal acquaintance with its properties.

The attractive power of the loadstone is readily noticed by placing it amongst some iron-filings: these will at once arrange themselves in symmetrical forms at the extremities of the stone, and adhere to it with a considerable force. The form of the curves is best seen by placing a sheet of paper on a piece of the loadstone, or over the ends of a common horse-shoe magnet. If the paper be then gently tapped, the filings will instantly arrange themselves in the form represented in the following cut.

It will be noticed, if iron, but *not steel*, filings be employed for the above purpose, that the moment the natural or artificial magnet is removed, the filings are incapable of assuming, of themselves, such curves, if these be first destroyed by shaking them. It is hence evident, therefore, that the peculiar curves they assumed were entirely due to the influence of the magnet; that these were not permanent; and, in fact, that the effect resulted from the *induction* of magnetic phenomena, caused by the force resident in the magnet.

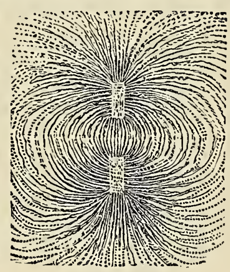


Fig. 184.

If a needle be suspended by a string, and the natural magnet, or loadstone, be brought near to it, the needle will be attracted, or, more correctly, they each attract the other; for the needle exercises as much power, for its bulk, on the loadstone, as the latter does on the needle. Precisely the same law rules all attractions. Thus, although we say that as an apple falls to the earth, the latter attracts it, still the apple also, but not equally, attracts the earth; but as the mass of the apple is so exceedingly small, its effect on the earth is imperceptible to our senses, or our most refined instruments. Nevertheless, that such a law of action is true, is readily proved by measuring the attraction of a mountain on a plummet, suspended freely. If the mountain exercised, by its mass, no attraction on the plummet, the latter would hang perpendicularly in a line running to the centre of the earth. But, experimentally, under the circumstances above named, such is not found to be the case; for it has been shown, by careful experiments, that a plummet is deflected, from a straight line, towards the mountain. Now, the latter, in all cases, can only be a fractional part of the mass of the earth, and yet it opposes the attraction of the latter to the plummet; hence in gravitation, as in magnetic attraction, action and reaction are equal, although, under many circumstances, the fact may be with difficulty, or not at all, demonstrated.

The phenomenon of magnetic attraction may also be readily illustrated by gently placing a needle on the surface of water in a basin. If a piece of iron be presented to it, and neither the needle nor the iron be in the least magnetic, no effect will be observed. But if a piece of loadstone be brought near to the outside of the basin, although the solid matter of the latter intervene between the loadstone and the needle, still the latter will move towards the loadstone, and as it gets near to the latter, its speed will be greatly increased. Possibly, resulting from this, the needle will strike the basin with such force as to cause it to sink in the water. We may here explain the reason the needle so floats on the water is, it is surrounded with a thin film of air, that usually exists on all polished surfaces, and, in this case, is sufficient to suspend the needle on the water, although, bulk for bulk, this has only the one-seventh weight or specific gravity of the iron.

It will be noticed, on placing the loadstone in the iron-filings, that the attraction is greatest at two points. These are termed the *poles* of the magnet, whether natural, or as found in horse-shoe, bar, and other forms of magnets. The question of magnetic polarity is one of the highest importance in the science. It is only here mentioned for the present, but will receive extended investigation hereafter.

Respecting the amount of attractive power exerted by the natural magnet, or loadstone, it has been remarked, that "the smallest loadstones generally have a greater attractive power, in proportion to their size, than larger ones. They have been found of such strength, that though weighing only about twenty-five grains, they could lift a piece of iron about forty-five times heavier than themselves. A small magnet, set in a ring, and worn by Sir Isaac Newton, is said to have been capable of lifting 746 grains, or 250 times its own weight; and it is stated by Cavallo, that he had seen a loadstone which weighed only about six and a-half grains, that lifted a weight of 300 grains." Again, "Natural loadstones often possess unequal powers of attraction in different parts of the mass, in consequence of want of homogeneity of structure and composition. Hence a portion has often been cut from a large loadstone, which could lift a greater weight of iron than the large one itself, the portion detached having possessed the most suitable structure, and the other part having weakened the action of the powerful part by keeping the body to be lifted at a greater distance from those points where the magnetism was strongest. It is, no doubt, from a similar cause that small magnets have a greater proportional power than large ones, or that those of two pounds weight have seldom been found capable of lifting more than *ten* times their own weight of iron."

But not only has the loadstone an attractive force. It also exercises a repelling one. Thus,

if two pieces of it be floated on a cork in a basin, it will be found that, when they are in certain positions, they will rapidly attract each other. But if one of them be then turned round, so as to present an end exactly opposite to that it had previously done to the other, then the two will mutually repel. Hence, besides magnetic attraction, there is also magnetic *repulsion* resident in loadstones.

It has already been noticed, that when a natural magnet is placed in iron-filings, it arranges the latter in definite forms at two opposite extremes, that have been termed *poles*. Now, if one of the pieces of loadstone be removed from the basin of the last experiment, and the other be left free to take up any position, it will be found that it will arrange itself in a line, one end of which will be a little to the left of true north, as shown by the pole-star ; whilst the other end is at a little to the right of due south. Hence we discover the *polarity* of the loadstone ; or, in other words, its tendency to assume a certain position, apparently in obedience to some unseen force. The latter is, as we shall subsequently more fully explain, the magnetic power of the earth exerted on the magnet, and equally the magnetic power of the latter exerted on the earth. There is, therefore, a definite directive influence exerted on the needle : it is also constant ; for, no matter how often it may be deflected by the hand from the direction it assumed, it will return to that direction on any hindrance being removed. The same facts may equally be shown and repeated by suspending the loadstone from a string, when the phenomena of attraction, repulsion, and polarity will be at once observed.

The two extremities or poles, consequent on the directive power thus shown, have been distinctively named. That which points to the north, is called the *north pole*; and that to the south, the *south pole*—terms familiarly known in connection with the ends of the needle in the ordinary mariner's compass.

It is evident, then, from the preceding facts, that the poles or extremities of the loadstone possess distinct and separate, yet, in another sense, identical powers. Each can attract and repel, and also possesses directive power. Like electricity, in which we have the vitreous and resinous forces, so have we a north and south magnetism. But the analogy is still further carried out, as may be learned thus :—

If a body be electrified by presenting to it (as, for example, a feather suspended by a silk thread) a piece of dry glass tube that has been excited by friction, the feather will be attracted to the glass. If another feather, *similarly* electrified, be presented to the first, it will be found that the two *repel* each other. If, however, the other feather had been electrified by having had presented to it a piece of sealing-wax rubbed like the glass tube, and it be presented to the first, electrified by the tube, then the two feathers will at once *attract* each other. Now, here we find that the feathers are in *opposite electrical states* ; one being excited by *vitreous*, or glass-excited, and the other by *resinous*, or resin-excited electricity. Hence we gather that *similarly* electrified bodies repel each other, whilst *dissimilarly* electrified bodies attract each other. So, in magnetism, *similarly* named poles repel, and *dissimilar* poles attract, each other. This is one of the many conditions that will hereafter be examined, which show us, not only the analogy between electricity and magnetism, but the almost identity and convertibility in respect to the phenomena they separately and collectively exhibit. Further, we shall see that magnetic attraction and repulsion are, like the similar effects of electricity, the consequences of induction.

So far we have only dealt with the phenomena exhibited by the loadstone, or natural magnet. We next turn to consider how its influence can be communicated to iron and other bodies ; but, in the latter case, to a much more limited extent than in respect to iron.

An ordinary needle, if quite free from magnetism, floated on a basin of water, will remain indifferently in any position it may be placed. If, however, it be rubbed gently with a piece of loadstone, and then replaced on the water, it will be found that it has acquired entirely new properties. Like the loadstone itself, it will tend to maintain a position nearly north and south, and return to that position whenever it is left free so to do. It has, therefore, evidently acquired the property of polarity.

If, again, one end of the loadstone be presented to one of its ends, the latter will be attracted or repelled, according to whether the opposite or similar poles of the needle and loadstone are presented to each other.

If another needle be rubbed by the loadstone, and presented to the first, they will similarly repel or attract each other, showing that two magnetised bodies have been produced, exhibiting all the phenomena of the loadstone. Steel of any form, thus magnetised, constitutes an *artificial magnet*.

It is evident, therefore, that all the properties of the natural magnet, or loadstone, may thus be communicated to another body; but, for the present, a particular condition must be noticed that is essential for such an object.

We have seen that when the loadstone is taken away from the iron-filings, presuming them to be obtained from *pure soft iron*, all sign of magnetism is lost. If, however, we use steel, or very hard iron, the effect becomes permanent, or, at all events, by proper precautions, may be kept resident in the steel for an almost indefinite period. This will, in part, depend on the strength of the first source of the communicated magnetism. The quality of the newly-magnetised metal, and the use of proper methods in communicating the magnetism, are subjects that will hereafter be entered into in much further detail.

It must not be supposed that mere *rubbing* is the necessary effective agent in communicating the magnetism : on the contrary, although the resulting effect be less noticed, still the effect will take place. Thus, suppose, as in the following cut, No. 1 represents an ordinary bar artificial

magnet, and No. 2 a bar of soft iron or steel. As soon as the north pole, N, of the magnet approaches No. 2, it induces in the latter polarity. At *s*, in No. 2, a south pole will be produced;

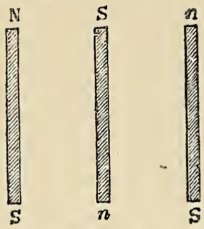


Fig. 185.—Magnetic Induction.

and at *n*, in No. 2, a north pole will exist. If No. 3, another bar of iron or steel, be similarly approximated to No. 2, the latter will produce in it the south and north poles, as indicated by the letters.

Now, here we have a most interesting result, which is called *Magnetic Induction.* By this we mean that the approximation of a magnetised body to an unmagnetised one, if of suitable materials (as iron or steel), induces in the other polarity of opposite denomination in respect to adjacent poles; that is, a north pole, presented under such circumstances, *induces* a south pole in the adjacent bar of metal; and this, again, has the power of inducing the same effects on another bar of iron.

If pure soft iron be employed, then the induction will be but temporary: thus if the bars 2 and 3, as represented in the preceding cut, be of soft iron, and a few iron-filings be sprinkled at their extremities, it will be found, that at the instant magnetism is induced, the filings will assume the polar and curved position already represented at p. 163, Fig. 1, *ante.* But the moment the magnetising bar is removed, the filings will fall down, uninfluenced by the iron, for the latter has lost the induced magnetism it had previously possessed.

From this fact, it is evident that the attraction exercised by the iron results from the magnetic induction that was exerted on it. Its temporary magnetism was not an inherent quality, for it was lost as soon as the inductive influence was removed. We also see that, by virtue of this induction, the magnetic properties may be propagated readily from one piece of iron to another, as illustrated in the bars and the filings; for the reason that these assume the figures to which we alluded, and illustrated, is, that each separate filing becomes an individual magnet, the pole of one attracting the pole of the next, which, under the circumstances just explained, *must* be of opposite denomination, simply because both are the result of induction.

Here, again, we must notice the analogy of magnetism with electricity. Supposing that, in

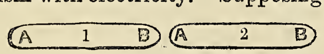


Fig. 186.—Electrical Induction.

the above figure, an excited glass tube be presented to an insulated body, No. 1, at A; at the other extremity, B, an opposite condition of electricity will be excited, and the induction will proceed to another body, No. 2. Their electricity will, at the two adjacent poles, be in opposite electrical states; consequently, two light feathers placed respectively one on each of the adjacent ends of No. 1 and No. 2, will attract each other, because by induction they are placed in opposite electrical conditions. Hence we see precisely similar circumstances in electrical and magnetic inductions, still further showing the analogy that subsists between these two remarkable forces of nature.

Here we may make a few remarks, parenthetically, on the peculiarity which attends magnetic and electric induction, that distinguishes them from all the other forces of nature. Of gravitation we only know its attractive power as exerted between masses; but we have no reason to suppose that the principle of repulsion exists, nor can we see any inductive form of the exercise of that force unless we assume (which has been done) that gravitation is identical in cause and nature with magnetism. The same may be said of mechanical cohesion and chemical affinity, in both of which we have attraction, only altered, suspended, or modified by mechanical or chemical causes. In capillary attraction we have also, apparently, its opposite, repulsion, as of mercury in a glass vessel; but no such phenomena as induction can be traced. The same must be remarked of light and heat; and thus, as before observed, *induction* is the great characteristic of magnetism and electricity.

The peculiarity of magnetism arises from induction. The greater the induction that goes on, the larger is the amount of attractive force generated, and the longer it is retained. Hence, as is well known, a small piece of soft iron is always attached to the end of a horse-shoe magnet, called its keeper. Again, because of the inductive powers of two opposite or dissimilar poles on each other, the attractive force of two magnets is greater than the repulsive force. Sir David Brewster remarks thus repecting this:—"In comparing the amount of the attractive force of two *dissimilar* poles of two magnets with the amount of the repulsive force of the two similar poles, it has been found that the former force is considerably greater than the latter. This result is a necessary consequence of the inductive process, already described. When the two attracting poles are in contact, each magnet tends to increase the power of the other by developing the opposite magnetisms in the adjacent halves, and thus increasing their mutual attraction. But when the two repelling poles are brought into contact, the action of each half, brought into contact, has a tendency to develop in the other half a magnetism opposite to that which it really possesses, and thus to diminish the two similar principles, and weaken the repulsive power. This injurious influence of opposite poles upon the repulsive power of the magnets in action, is finely exhibited when one of the magnets is very powerful and the other very weak. When the two similar poles are held at a moderate distance, a repulsion is dis-

tinctly exhibited; but when they are brought into contact, the stronger attracts the weaker magnet—an effect which is produced by its actually destroying the similar weak magnetism in the half next to it, and inducing in that half the opposite magnetism, which, of course, occasions attraction."

It hence follows, that if we wish to keep any form of magnet in as highly a magnetised condition as possible, we should prevent the loss of induction. Consequently, as before stated, a keeper is always desirable at the end of a horse-shoe magnet; whilst bar magnets, besides having keepers at the end, may be so kept as to be parallel to each other, and with the north pole of one adjacent to the south pole of the other.

The inductive action of magnetism as producing attraction and repulsion simultaneously, only, of course, at opposite ends, is very forcibly illustrated by a powerful electro-magnet; that is, one in which magnetism is induced by a powerful electro-current. But the same may be shown with an ordinary artificial magnet of the bar form. If two or three nails, or, still better, some pieces of iron wire, have their points in contact with one pole of the magnet, of course the pole of the magnet to which they are attracted will induce poles in them of an opposite character at the point of contact. But at their further extremity all these poles will be similar, and consequently they repel each other, so as to cause the wires to form a kind of cone, the imaginary base of which is at the extremity most distant from the magnet, whilst the apex is at the point of junction with the latter.

In respect to the distribution of magnetism in a straight or bar magnet, Brewster remarks—"It is very obvious, from the preceding experiments, that in regular magnets, with a north pole at one end and a south pole at the other, the two kinds of magnetism, north and south polar, are equally and regularly distributed, the one occupying the one half of the magnet, and the other the other half. It is obvious, also, that each kind of magnetism has no intensity [or power] at the centre of the magnet, or its middle part, and that it increases, according to some regular law, from that point towards the two poles at the extremities of the magnet." The exact position of the place of greatest magnetic intensity, in respect to each pole, will be more fully dealt with hereafter.

"The first person who determined the law of distributions which we have now mentioned, was M. Coulomb. The magnet which he employed for this purpose was a cylinder two lines in diameter, twenty-seven inches long, and its weight 1,946 grains; and he ascertained the intensity of magnetism at each point, from its middle to its extremity, by observing the number of oscillations which a small magnetic needle performed in a minute, when it was made to oscillate before different parts of the wire. He had previously observed the number of oscillations which the same needle performed out of the sphere of the magnet, and he considered the magnetic intensity as proportional to the difference of the squares of those two numbers of oscillations. The first needle which he employed was three lines in diameter and six lines long; and it was made of such a size, and of such hardness, that its magnetism should not be perceptibly altered by the action of the wire during the experiments; for if any change did take place, the results obtained at different points of the magnet could not be compared. The great length of twenty-seven inches was given to the magnet, in order that its remoter pole might be so distant from the needle that it would be unnecessary to make any allowance for its action upon the oscillations of the needle. In this way Coulomb obtained the following results:—

Distances from the North Pole of the Magnet.	Observed Intensity of the Magnetism at these distances.
0	165
1	90
2	48
3	23
4, 5	9
6	6"

The result that was attained can be exhibited in the form of a mathematical curve, the ordinates of which represent, by their increasing length, the gradually increasing form or intensity of the force as the extremity of the pole is arrived at. In repeating these experiments with magnets of the same shape and diameter, but of less length, all other circumstances being unchanged, Coulomb concluded, that whatever was the length of the magnet, provided it was greater than six or seven inches, the three inches at both ends, north and south poles, gave always the same results on the twenty-seven inch magnet. From this point towards the centre the magnetism became weak and insensible in all of them: and in very long magnets, he even found that the ordinates passed from positive to negative. M. Biot showed, "that the cause of intensity, as determined by Coulomb, results from the combination of two logarithmic curves, which, setting out from each pole of the magnet, would have their ordinates equal, and in an opposite direction. The intensities, calculated upon this supposition, agree exactly with the observed results."

The same eminent authority adds—"As Coulomb had examined the distribution of magnetism only in magnets of considerable size, M. Becquerel was desirous of ascertaining if the law was observed in steel wires of a small diameter, such as $\frac{1}{80}$th of a millimetre, or $\frac{1}{2000}$th of an inch. In order to procure such wires, he encased a steel wire one millimetre in diameter in a cylinder of silver, and having drawn out the whole into a wire, the silver was removed by means of boiling mercury. He employed the method used by Coulomb in determining the law of distribution; but, on account of the fineness of the wires, and the weakness of the magnetism which they acquired, he was obliged to make some changes in the method. He obtained, however, the very same results as those given by Coulomb.

"A number of interesting experiments on the distribution of magnetism have been made by M. Kupffer, of Kasan, by means of the method of Coulomb. He employed a flat and very narrow needle, twelve millimetres long, and he placed it at a horizontal distance of three decimetres from a cylindrical bar magnet of cast steel not tempered, 607 millimetres long, and 12½ millimetres thick. He began his experiments with magnets that possessed a weak degree of magnetism. In magnetising them, he rubbed the steel bar perpendicularly on the *north* pole of a very strong artificial magnet, and he replaced the bar vertically before the needle, the north pole of the former being uppermost. He found that the south pole was stronger than the north pole, and that the point of indifference, or the neutral point, was nearer the stronger pole than the other. Upon reversing the magnet, the magnetic intensities of its different points increased, and the neutral point approached the middle of the magnet. These changes were produced successively, and the magnet did not attain its final state till it had remained some time in the same position. Kupffer observed, that whenever the magnetic intensities of the bar increased, the neutral point slowly approached the middle point; that the point was always nearer the stronger pole; that a bar magnetised vertically was always more powerful when its north pole was downwards; and that a bar magnetised by the method mentioned above, was always strongest in the pole immediately produced by that magnet.

"After detailing his observations with a bar magnetised to saturation, he proceeded to determine the influence exercised by the form of the extremities of the bar on the magnetic intensity, and on the position of the neutral point. A cylindrical bar of the steel (cast, but not tempered) having been rounded at one of the ends, and magnetised to saturation, was placed fourteen centimetres from a magnetic needle, and in the line of its direction. When its north pole was directed to the south, the force of the rounded north pole was 2·0319, and that of the south pole was 2·1558. In the opposite position of the bar, the magnetic force of the north pole was 2·2198, and that of the south pole 2·3006, the neutral point being in the middle.

"The rounded end of the bar was now filed to a point, and made sharper and sharper in each successive experiment, after being each time magnetised to saturation. The force of the sharpened pole diminished with its acuteness. The neutral point receded always from this extremity.

"In order to ascertain the distribution of magnetism in the interior of the magnets, Coulomb formed sixteen rectangular magnets out of the same piece of steel. Each was six inches long, nine and a-half inches wide, and 382 grains in weight. They were annealed at a white heat without being tempered, in order that he might be certain of having them always in the same state. He magnetised them all to saturation, and formed bundles with a certain number of them, similar poles being placed together. The magnets in each bundle were bound tightly together with a strong silk thread. Each bundle was then placed in a torsion balance, and placed 30° out of the magnetic meridian. The force of torsion necessary to retain it in this position was a measure of its magnetic intensity. The following were the forces or degrees of torsion necessary to keep the different bundles at rest :—

	Degrees of Torsion.
1 magnet	82°
2 magnets united	125
4 ,, ,, ...	150
6 ,, ,, ...	172
8 ,, ,, ...	182
12 ,, ,, ...	205
16 ,, ,, ...	229

Hence it follows, that the magnetic force of each bundle increases in a ratio much less than that of the number of plates.

"Coulomb next determined the magnetic state of each of the magnets composing the bundles of eight and sixteen magnets; and he found that the two outermost magnets—those which formed the surface of the bundles—had a much greater force than the rest.

The first had a force which measured	46
The second	48
And the mean force of all the rest was	30

A single magnet had its directing force 82°; while, for sixteen of them united, the mean directing force of each was only 14°·3 ; that is, about the sixth part of the other.

"In examining the bundle of eight magnets by the method of oscillation, he found that the two outermost performed twenty oscillations in 90½ minutes; while all the rest performed the same number in from 211 to 278 nearly—showing the weakness of their magnetism. It is curious that the outermost but one had its poles reversed.

"Coulomb also found that a bundle of magnets will take nearly the same degree of magnetism as a single magnet of the same shape and weight; which leads us to believe, that in magnets of one piece, the magnetism diminishes from the surface to the centre, as in the precedingly described bundles of magnets."

For the preceding account of experiments intended to show how magnetism is distributed in magnetised bodies, we are indebted to Sir D. Brewster, as given in his *Treatise on Magnetism ;* and also for some of the following remarks on the effect of division and fracture of magnets.

If an ordinary bar magnet be broken in two at the centre, which, whilst the bar was entire, showed no sign of magnetic intensity, two magnets are formed, the extreme poles of the original bar being still the same in denomination ; whilst the two new extremities become two new poles, of course of opposite character to those forming the original and previous poles ; that is, the end of the new bar becomes a south pole, if the other extremity had been a north pole, whilst the end of the other bar receives a new north pole to the south pole at its other extremity, as contained in the original bar.

"When Æpinus made this curious experiment he did not divide the magnet in two; but he set two steel bars end to end, and magnetised them as one magnet, so that this compound magnet had its magnetism distributed as in a single bar. He then separated them, and found that each bar was a perfect magnet with two poles. Dr. Robinson repeated this experiment successively on some occasions; but he sometimes found indications of the compound magnet acting as two magnets. We are persuaded that this arose from an imperfect union of the two bars, and not from any defect in Æpinus's experiment. The united ends of the bars should be ground together, so as to be kept in perfect contact, and preserved in this state by powerful pressure during the time that they are magnetised. If this be done, we have no doubt that they will act on iron-filings, and throw them into curves as if they were a single bar, and even, by examination with a fine needle, exhibit the same regular distribution of magnetism that takes place in the most perfect magnet."

When first divided, the two poles are instantly developed at the two new extremities, as already explained; but the neutral points are nearer the interior poles, or near the neutral point of each magnet. But, in the course of time, a regular distribution of magnetism, as in the original bar, became effected.

This curious result is easily observed, on the small scale, by very simple means. If a good steel needle be well magnetised by rubbing it with a loadstone, in the manner already explained, or by a horse-shoe or bar magnet in the manner that will be eventually pointed out, of course its two extremities will become polar. If the needle then be divided at a point equi-distant from the two extremities—that is, in the centre of its length—the two portions will become two new magnets, illustrating the remarks, experimentally, that have just been made. Of course, the polarity and attractive or repulsive powers may be easily tested by means already pointed out, and the magnetic curves produced by iron-filings.

The curves or figures produced by magnetism on steel plates are very curious: they were first discovered by M. Haldat, of Nancy, and are analogous to electrical and acoustic figures. The discoverer employed plates of steel eight to twelve inches square, and from one-twentieth to an eighth of an inch in thickness. "The plates which he used were of that kind of steel which is used for the manufacture of cuirasses, so that it did not require to be tempered, being sufficiently hard to preserve the magnetism communicated to it. Figures of any kind may be traced on the surface of the steel plate, either by one magnet or by several combined; and the best form for this purpose is that in which the poles are rounded. In this way we may write upon a steel plate the name of a friend, or sketch a flower or a figure, with the extremity of a magnet. If it is a south pole that we use, all the traces which it makes will have north polar magnetism; and if we shake steel-filings upon the plate out of a gauze bag, the filings will arrange themselves in the empty spaces between the lines traced by the pole of the magnet, and thus represent in vacant steel the name which has been written, or the flower or figure which has been sketched. 'These figures,' says M. Haldat, 'have a perfect resemblance to those which are formed on the surface of non-magnetic plates—viz., wood, card, glass, or paper—under which a magnet is placed. The resemblance between the two sorts of figures, when the magnets and the parts magnetised have the same form, is not only exact in the whole figure, but even in the smallest details. The filings collect at the parts where the magnetism is most intense, they arrange themselves in pencils and radii, and form the same curves which we represented in Fig. 184, p. 332. These curves, and pencils, and rays, so similar at the two poles of the same magnet, have such a resemblance that they do not allow us to distinguish the two parts from one another.'

"M. Haldat has likewise produced these curves by interposing between the tracing magnets and the steel plates solid non-magnetic bodies, such as cards, glass, and even metallic plates that are not ferruginous. This method of producing magnetism in the steel plate by induction gives the same figures; but, in order to be efficacious, the magnet must have its pole carried parallel to, and at a small distance from, the plates of steel, and must repeat its traces in order that the magnetism may be sufficiently deposited. For rectilinear figures, M. Haldat employed rules with grooves, which keep the motion and distance of the bar invariable; for curvilinear figures he interposes some thin and uniform plates; and he can vary the distinctness of the figures by varying the distance of the tracing-pole of the magnet.

"In sifting the iron-filings upon the steel plate, a gentle vibration of the plate, by tapping its edge with the ring of a small key, will assist the filings in taking their proper places. But we must avoid such vibrations as will produce regular acoustic figures, unless we wish to unite the magnetic and acoustic figures, which produces very interesting and varied forms.

"The magnetism of the plates so produced may be subsequently removed by heating the plate until it acquires a straw colour. It may also be effected by beating it with repeated blows of a wooden hammer, the vibrations thus caused gradually removing the magnetism.

"As the figures traced on the steel are nothing more than magnets of different forms, and are surrounded on all sides with a substance capable of acquiring the magnetism which may be developed by communication, we might expect that this means of communication between the opposite poles of the magnets would bring them into a neutral state. This, however, is not the case, and the portion of the metal which surrounds the magnetic figure performs the part of the *armature* of a loadstone, and the magnetism is thus kept up. If the figure be a simple rectangle, like that of a bar magnet, the state of the plate,

examined with a small needle, is exactly the same as a bar magnet, and the parts which surround this magnetic portion are in a neutral state, as if unconnected with the rectangular space; from which it follows that the magnetic virtue, which communicates itself so easily by influence, ceases to communicate itself between the continuous parts of a magnetisable body, of which one portion is magnetic, and the rest in a neutral state.

"In carrying into effect the preceding method of making magnetic figures, a very great difficulty must be experienced in recollecting the invisible traces made by the pole of the magnet, so as to complete a regular figure or drawing. When the figures are made *immediately*, as M. Haldat expresses it—that is, by the actual contact of the pole of the magnet, without any intermediate body—the best method would be to cover the plate of steel with the slightest coating of grease, and sift upon the surface, through a linen bag, some of the finest flour. The pole of the magnet, while tracing the figures on the steel, will remove the flour, and thus exhibit to the eye an accurate picture of what it has traced; and it will thus be easy to make the magnetic figures more distinct by repeating the traces with the magnet. The same thing may be done by putting an etching-ground upon the steel plate, and tracing the figures as before. When the figure is completed, the coating of grease and flour, or the etching-ground, must be removed previous to the application of the iron-filings.

"When the figures are to be produced *mediately*, or by the intervention of a non-magnetic substance, such as paper, card, wood, or glass, a fine dust may in like manner be laid on the surface; but when the interposed matter will receive the mark of a pencil or sharp point, it would be preferable to attach to the cylindrical pole of the tracing magnet a very short point of a non-magnetic substance, which would make a visible mark on the paper, card, or wood, without strewing any fine dust on the surfaces. By the use of such a point, indeed, we may dispense altogether with the interposed substances, and communicate the magnetism by induction to the steel plates, in the very same way as if it had been done by the intervention of a non-magnetic plate, whose thickness is equal to the length of the short point or tracer affixed to the pole of the magnet.

"The magnetic figures might either be rendered permanent by covering the steel plate either with a gummy or varnish solution, which will indurate by exposure to the air; or with a coating of some easily melted substance which becomes fixed at ordinary temperatures. If we sift the iron-filings on the steel plate, when covered with such fluid, the filings will take their magnetic position round the traced lines, and will become fixed by the induration or solidification of the fluid coating."

We have thus given a general account of all the leading phenomena of magnetism, as existing in the loadstone naturally, and by artificial communication to iron and steel by the inductive action of either a natural or artificial magnet. We have not thought it necessary, in this general view of an introduction to magnetic phenomena, to enter into any description of the methods of making magnets for every purpose that we have yet supposed. A child's common horse-shoe magnet, or a piece of loadstone (either of which may be purchased for sixpence), a few steel sewing and knitting-needles, and some find thread to suspend them, will be amply sufficient to give the reader every aid in the early experiments that have been suggested for trial.

Of course, in attempting to follow the more scientific departments of magnetism, a very different class of apparatus is requisite; and the refined manner in which these are now constructed, has afforded us some most valuable results, not only in the study of the magnetism of the earth (or *terrestrial magnetism*, as it is called), but also in that of the relation which subsists between the magnetic character of the earth, and its changes with those of the sun. It has been perfectly demonstrated that our earth is really an immense permanent magnet; and it is the action of its induction at the magnetic poles, and by diffusion towards the magnetic equator, that the phenomena of magnetic polarity depends on. Our needle really points with its south pole to the north pole of the magnetic earth; so that what we call the north pole of our needle is really a south pole; for, as already pointed out at p. 333, *ante*, it is only dissimilar poles that attract each other.

Again, as we proceed, we shall find that we possess another instrument in the dipping-needle, that enables us to test the intensity of magnetic force at any part of the earth's surface that we please; for it will be found, that a needle suspended vertically or perpendicularly, instead of horizontally, points to positions, in various parts of the earth, constantly varying from, and inclined at, an angle to the natural axis of rotation of the earth. By exploring various parts of the earth with such an instrument, we can find out the point of the greatest intensity of terrestrial magnetism, and, in fact, discover, to a nicety, the position of the magnetic poles—a matter of high importance, not only in the study of the science, but also as affecting navigation, &c.

For a complete understanding of the laws of magnetism, and their full investigation, of course a considerable knowledge of mathematical science is requisite. All forces in nature, of a radial character, act in such a manner that their values may be made the subject of calculation, not simply according to arithmetical rules, but also in connection with geometry, trigonometry, algebra, the differential calculus, &c. Many persons ignorant of the value of such an aid, perceive frequently, in the employment of such methods in connection with the study, a certain amount of pedantry. But the idea is erroneous; for the laws of mathematical philosophy may frequently lead, by this precision in application, to discoveries of a practical nature. A remarkable instance of this occurred in the discovery of the most external planet of our system —Neptune—some years ago. Disturbances in

the periodic movements of an adjacent planet could not be accounted for by any result obtained by observation. But by the application of mathematical reasoning, founded on the known laws of gravitation, the place where a supposed new planet should be found, if it really existed, was pointed out with such precision, that, when the telescope was pointed thitherward by a practical astronomer, he at once hit on the expected stranger, and confirmed one of the greatest triumphs that human intellect ever accomplished.

Similarly, in certain departments of the science of magnetism, a knowledge of mathematics is of the highest value. We shall endeavour to avoid, as far as possible, all such technicalities, and introduce them only when absolutely necessary.

It will next be advisable, in the order of the study of the science, to enter on a description of the various methods that have been proposed to make artificial magnets of much greater attractive powers than any which have yet been mentioned.

MAKING ARTIFICIAL MAGNETS.

When the attractive power of the magnet, as communicated to steel, became studied by philosophers, it soon was desired to produce magnets of great attractive power, so that the phenomena and laws of magnetism might be completely known.

It has already been shown, at p. 333, *ante*, how readily a piece of steel may be magnetised by rubbing it with a natural magnet, or loadstone; and that when the steel has such force communicated to it, another piece of steel may be magnetised by it through induction.

It is on this principle that all artificial magnets are made; but great difficulty occurs in the practice of the method. Hence numerous plans have been proposed, that we shall investigate in detail.

But, before doing so, we may define the chief forms that are given to magnets, and the names that have been assigned to them according to their forms.

A *Bar magnet* consists of a straight piece of steel, either round or flat, the two extremities of which are the most distant parts of the magnet. The former is illustrated in a needle or ruler. The length and thickness are regulated according to the power or purpose required.

The *Horse-shoe magnet* is so called because it is of the form of a horse-shoe. In it the extremities, or poles, are close together, as represented in the annexed cut, in which N and S are the poles of the magnet. Now, it is evident that such a form of magnet will exercise a much greater attractive power than a bar magnet; first, because, in the horse-shoe form, both poles act simultaneously; and, next, because, by the proximity of dissimilar poles, they act inductively on each other, and increase the intensity of their magnetism, for reasons already pointed out at p. 334, *ante*, when we explained why the repulsive force of two magnets is less than the attractive force. All horse-shoe, and, indeed, every other form of magnet should have a piece of soft iron at either and both poles (according to the form) constantly, when not in use; the reason of which has been explained at p. 335, *ante*.

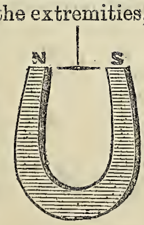


Fig. 187.

The *Compound magnet* is that in which a number of bar or horse-shoe magnets are arranged parallel to each other. Usually the horse-shoe form is the most common. It is represented in the annexed cut; N and S being the poles, and K the *keeper*, or *armature*.

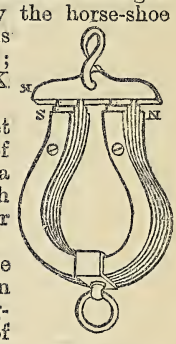


Fig. 188.

The early form of bar magnet was made by placing a piece of hard steel, horizontally, on a table, and then rubbing it with an already magnetised bar throughout its length.

The extent of magnetic force so communicated depends on the size of the loadstone or magnetised bar, and of the piece of steel which is magnetised. In every instance in which force of any kind is communicated to any body, there is a definite relation between the body possessing and that receiving a force, with respect to their mass. This is a natural consequence of the constitution of any mass, because its atoms have, either chemically or dynamically, a fixed amount of attractive power, which they can exert on any proximate atom within their influence. This power can be mathematically calculated. The circumstances may vary considerably, but the laws are in every case constant; and the attraction of gravitation is, perhaps, the best illustration which we can adduce to prove our position. For instance, we may suppose that any body exerts an attractive power on another near to it. Such a power must necessarily have some relation to the mass or other qualities of the body which it attracts, and the distance existing between. This relation or comparative effect of force may be ascertained in a variety of ways. In the case of gravitation, the time occupied by any body in falling from any height, may become a measure of the force. In respect to magnetism, resistance to torsion, the number of oscillations made within a given time of a magnetised bar, and other means that will afterwards be pointed out, are adopted as a measure of the force in a magnet.

The simple method that has been described of producing another magnet by merely rubbing an already magnetised piece of steel on it, is very ineffective if we wish to get the greatest amount of magnetism communicated to the new bar. In fact, only a slight amount of the force is induced. It often happens, that instead of the whole intensity of the force being accumulated at or near the poles, it is spread in different points on the bar throughout its whole length, and consequently only a limited amount of effect can be obtained.

The method of simple contact was also adopted —that of placing the bar intended to be magnetised between the poles of two separate bar magnets; the north pole of one being in contact with one end of the bar, and the south pole touching the other end.

Knight's method was a great improvement. He tempered the steel at a cherry-red heat, and, when cool, placed the bar on two equal-sized magnets, so that the line joining their north and south poles, which were in contact, should just be over the centre of the bar to be magnetised: the magnets were then removed to each extremity of the bar, the operation being frequently repeated. The amount of effect will be proportionate to the size of the magnets employed in relation to that of the bar being small; and if powerful magnets are used to magnetise a small bar, they saturate the latter with the magnetic power.

Duhamel's method was that of placing two bars to be magnetised parallel, and at a little distance from each other, on a table, and joining their two ends at each extremity by a piece of soft iron; so that the figure formed by the whole arrangement would be a parallelogram, of which the bars to be magnetised form the largest size. Two bundles of bar magnets were then pressed to the centre of each bar, and withdrawn to the extremities; the magnetism taking place from the centre of the bars to the poles, and not along the whole length at one operation, as in the simple plan described at p. 339, *ante*. By this method a large amount of magnetism may be communicated, and the use of the small end-pieces of soft iron greatly assists the effect. Horse-shoe bars may be magnetised by a modification of this method.

The double-touch method of Mr. Michell is still constantly practised. He joined together two bundles of magnetised iron bars, separated by a distance of a quarter of an inch; and placing a number of steel bars end to end, and in contact, these were rubbed backwards and forwards through the whole length of the bars. By this method the middle bars acquired the greatest amount of magnetism; and the end ones can also be equally saturated by making them form the middle in a subsequent operation.

Canton improved on this process by a somewhat complicated method; as did also Æpinus. Coulomb proposed to magnetise a bar by placing it horizontally between two sets of bar magnets, so that the steel bar should be in contact with the north pole of one set, and the south pole of the other. He then took two other sets of magnets, and, commencing at the centre of the steel bar, rubbed it from there to its extremity with the bars; that is, one bundle of magnets travelled to each extremity simultaneously. The bars were first carefully tempered at a cherry-red heat. On this process M. Biot improved considerably, especially in respect to the production of large compound magnets.

By means of percussion, Dr. Scoresby, the late eminent arctic navigator and magnetician, proposed a ready and effective means of inducing magnetism. It may be familiarly known to many of our readers, as an old experiment, that if a good steel poker be held by a string pointing west of north, and east of south—that is, in the magnetic meridian—and it be smartly struck with a hammer, it will afterwards show magnetic properties. In our day, when iron ship-building is so universal, this fact gives rise to serious consequences; for, as we shall subsequently explain, an iron vessel, if built in a certain direction, will become magnetic.

Dr. Scoresby's method is described by himself thus:—"I procured two bars of soft steel, thirty inches long and an inch broad; also six other flat bars of soft steel, eight inches long and half an inch broad, and a large bar of soft iron. The large steel and iron bars were not, however, absolutely necessary, as common pokers answer the purpose very well; but I was desirous to accelerate the process by the use of substances capable of aiding the development of the magnetical properties in steel. The large iron bar was first hammered in a vertical position: it was then laid on the ground with its acquired south pole towards the south, and upon this end of it the large steel bars were rested while they were hammered: they were also hammered upon each other. On the summit of one of the large steel bars, each of the small bars, held also vertically, was hammered in succession; and in a few minutes they had all acquired considerable lifting powers. Two of the smaller bars, connected by two short pieces of soft iron in the form of a parallelogram, were now rubbed with the other four bars, in the manner of Canton. These were then changed for two others, and these again for the last two. After treating each pair of bars in this way for a number of times, and changing them whenever the manipulations had been continued for about a minute, the whole of the bars were at length found to be magnetised to saturation, each pair readily lifting above eight ounces.

"In accomplishing this object, I took particular care that no magnetic substance was used in the process. All the bars were freed of magnetism before the experiment; so that none of them, not even the largest, produced a deviation of five degrees on the compass at three inches distance. Any bars which had been strongly magnetised, and had their magnetism destroyed or neutralised (either by hammering, heating, or by the simultaneous contact of the poles of another magnet placed transversely), I always found had a much greater facility for receiving polarity in the same direction as before, than the contrary. Hence it generally happened that one blow with the original north end downwards, produced as much effect as two or three blows did with the original south end downwards."

"By this ingenious process," says Sir David Brewster, "any person who has no magnets within his reach may communicate the strongest degree of permanent magnetism to hard steel bars of any magnitude, the bars magnetised by percussion being employed, as in the process of Coulomb, to magnetise the large bars which are required."

The preceding are some of the many methods that have been proposed for making bar magnets, single or compound; the latter consisting of a number of the preceding bound together by a band of brass, with their extremities or poles, of course, exposed.

Horse-shoe magnets, from their form, require a different method. They are the most convenient and powerful in producing a good compound magnet, or magnetic battery; and not only so, they are generally by far the best kind for communicating magnetism to steel. In the magneto-machine, now so largely used for electro-metallurgical purposes, &c., a compound bar of horse-shoe magnets is usually employed.

The form of a horse-shoe magnet, and of a compound magnet, or magnetic battery, has already been illustrated at p. 339, *ante*, by Figs. 187 and 188.

"In order to form a powerful magnetic battery, the best way is to unite a number of similar horse-shoe magnets, with their similar poles together, and to fix them firmly in a case of copper or leather. The following is the method recommended by the late Mr. Barlow:—

"He took bars of steel, twelve inches long, and having bent them into horse-shoe shape, their length was six inches, their breadth one inch at the curved parts, and three-fourths of an inch at their extremities, with a thickness of one-fourth of an inch. They were filed very nicely, so as to correspond, and lie flatly on each other. They were then drilled with three holes each, and, by means of screws passing through these holes, nine horse-shoe bars were bound together. When the heads and ends of the screws were constructed, so as to leave the outer surfaces smooth, the mass of bars was filed as if they were one piece, and the surface made flat and smooth. When the bars were separated, they were carefully hardened, so as not to warp; and when they had been well cleaned, and rendered bright, but not polished, they were magnetised separately in the following manner:—When the two extremities of the bars are connected by a piece of soft iron [as a keeper], the magnetism may be developed in the two halves by Duhamel's method; or, following Æpinus, we may apply a strong magnet to each pole [see *ante*, p. 340], and connect their extremities either with a piece of soft iron, or another magnet; or we may apply two horse-shoe magnets to each other, uniting the poles, which are to be of contrary names.

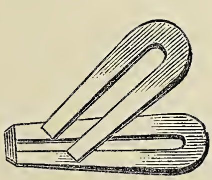


Fig. 189.

"When the magnet or magnets are prepared in any of these ways, they are then to be magnetised with another horse-shoe magnet, by placing its north pole next to what is to be the south pole of one of the horse-shoe bars, and then carrying the movable magnet round and round, but always in the same direction. [This method is illustrated in the following cut:—]

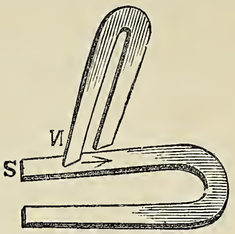


Fig. 190.

"In this way a very high degree of magnetism may be communicated to each of the nine bars. When this is done they are to be reunited by screws, and their poles or extremities connected by a piece of soft iron," as shown in Fig. 188, *ante*, p. 339.

A very curious and interesting result was obtained, by Dr. Knight, in forming artificial magnets from a kind of iron paste. According to Sir David Brewster—"Although the following method of making a magnetic paste has been given in almost every treatise on magnetism, and was kept a secret by its inventor, yet we have no distinct information that it was found superior, in any respect, to steel as a vehicle of magnetism. Mr. Benjamin Wilson communicated the method to the Royal Society, after the death of Dr. Knight."

The following directions are given to produce this curious imitation—at least we must so consider it—of the natural magnet, or loadstone:—

"Having provided himself with a large quantity of clean filings of iron, Dr. Knight put them into a tub that was more than one-third full of clean water; he then, with great labour, worked the filings to and fro for many hours together, that the friction between the filings of iron by this treatment might break off such small parts as would remain suspended in the water for some time; the obtaining of which very small particles in sufficient quantity seemed to him to be one of the principal desiderata in the experiment. The water being, by this treatment, rendered very muddy, he poured it into a clean earthen vessel, leaving the filings behind; and when the water had stood long enough to become clean, he poured it out carefully, without disturbing such of the iron sediment as still remained, which was now reduced to an almost impalpable powder. This powder was afterwards removed into another vessel, in order to dry it; but as he had not obtained a proper quantity of it by this first step, he was obliged to repeat the process many times. Having at last procured enough of this very fine powder, the next thing to be done was to make a paste of it, and that with some vehicle which could contain a considerable quantity of the phlogistic principle. For this purpose he had recourse to linseed oil in preference to all other fluids. With these two ingredients only he made a stiff paste, taking particular care to knead it well before he moulded it into convenient shapes.

Sometimes, while the paste continued in its soft state, he would put the impression of a seal on several pieces, one of which is in the British Museum. This paste was then put upon wood, and sometimes on tiles, in order to bake or dry it before a moderate fire, at about a foot distance. The doctor found that a moderate fire was most proper, because a greater degree of heat made the composition frequently crack in many places.

"The time necessary for baking this paste was generally five or six hours before it attained a sufficient degree of hardness. When that was done, and the several baked pieces were become cold, he gave them their magnetic virtue in any direction he pleased, by placing them between the extreme ends of his magazine of artificial magnets, for a few seconds or more, as he saw occasion. By this method the virtue they acquired was such, that when any one of these pieces was held between any of his best ten-guinea bars, with its poles purposely inverted, it immediately of itself turned about to recover its natural direction, which the force of these very powerful bars was not sufficient to counteract. After giving the preceding method, M. Biot remarks that it consists in procuring a very fine powder of iron a little oxidated, all the particles of which he united by means of linseed oil, or any other substance fitted to give them a proper degree of oxygenation. 'When this paste was magnetised,' he continues, 'each particle of the powder became a small magnet, in which the development of the magnetism might be very powerful, on account of the suitable degree of coercive power produced by the oxygenation; and the homogeneity of this state in all the particles, as well as their extreme tenuity, might give to the whole system the most favourable arrangements for receiving a high degree of magnetism.' M. Biot conceived that a somewhat analogous effect might be obtained by steel of an equal and homogeneous grain, the carbon giving a coercive power like oxygen; but he thinks that the paste is likely to form better magnets. He is of opinion, also, that some powerful natural magnets may owe their virtue to the union of similar qualities.

"Dr. Fothergill, who had seen Knight's paste magnets in his own possession, says that the mass had an appearance of a piece of black-lead, though less shining. * * * Conceiving that the powder, which formed the basis of this paste, was the black oxide of iron, Cavallo gave the following recipe for imitating natural magnets:—'Take some Martial Æthiops [the black oxide of iron], reduced into very fine powder, or * * * the scales which fall from red-hot iron when hammered, and are abundantly found in smiths' shops. Mix this powder with drying linseed oil [that is, linseed oil after boiling with litharge], so as to form it into a stiff paste. * * * This done, put it into a warm place for some weeks, and it will dry so as to become very hard. Then render it magnetic by the application of powerful magnets, and it will acquire *considerable* power.'"

We might continue, to a considerable extent, the various methods that have been proposed for communicating magnetism permanently to steel; but the space required for such a purpose may be better employed. It is more than likely that the majority of our readers will supply themselves with magnets purchased from the instrument-maker, who, making it his business to manufacture them, and having the advantage of long personal experience, will be far more likely to succeed in such matters than a beginner or amateur in the art. In fact, to be plain-spoken, the latter must serve a long personal experience before he is likely to exceed the results obtained by the practical man. Consequently, the preceding remarks, &c., must be considered as aids in accidental requirements, rather than as a direct course of instruction in making artificial magnets.

But one method has yet been unnoticed, of making artificial magnets, in this chapter. It is that by which the voltaic current is made instrumental towards that result.

The method of producing temporary and permanent magnetism by the voltaic current is remarkably simple in practice. If we coil round a bar of soft iron, covered by a sheet of paper, copper wire, so that each convolution of the coil be separate, and not touching each other, and connect the two extreme ends of the coil with any form of a voltaic battery, or even a single cell, the moment the current passes, the iron is immediately magnetised, and is capable of showing all the phenomena of a magnetised body.

The mode of making such an arrangement, in which *a a* represents the bar of iron, *b b b* the coil of wire, and *c d* its ends, is shown in Fig. 191.

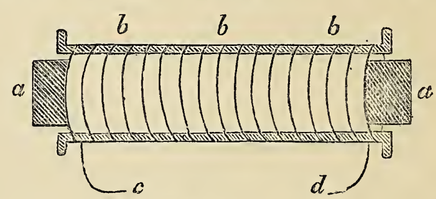


Fig. 191.

It is usual, in place of covering the bar of iron with a piece of paper, to coat the wire with cotton or silk, by which the metallic contact of each convolution of the wire is rendered impossible. Covered wire may be readily purchased of any of the philosophical instrument-makers.

A convenient mode of making the experiment is that of coiling the wire, covered with cotton or silk, round a wooden or gutta-percha tube, into the centre of which the object to be magnetised can be placed. If this be a piece of soft iron, then the magnetism imparted to it will only be temporary. If a piece of steel replace the soft iron, permanent magnetic effects will be imparted.

In all cases, however, the result is usually inferior to that which is produced by methods already explained for communicating magnetism to steel. The reason of this is by no means fully understood; but there remains the fact.

Electro-magnets of the horse-shoe form, so made, have enormous attractive power. Their shape is represented by the annexed engraving. The bent piece of iron is encircled with a coil (single in the cut) of copper wire, covered with cotton, the extremities of which, *a b*, are connected with the wires of a voltaic battery. Such an arrangement is easily made by covering an ordinary horse's shoe with a coil of covered copper wire. The ends, *c d*, should be filed down, so as to present an even surface. Of course, no magnetic effects are evident until a voltaic current passes by the wire round the iron; but then a great attractive force becomes evident. An electro-magnet of soft iron, that we possessed some years ago, was made of very pure iron, whilst the encircled copper wire was also very pure. Its form is represented in Fig. 193. In the absence of the

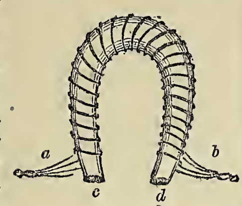


Fig. 192.

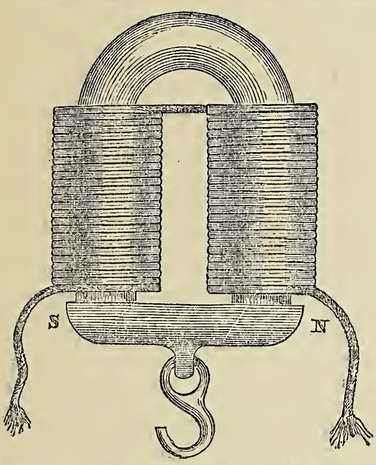


Fig. 193.—Horse-shoe Electro-Magnet.

circulation of the voltaic current, no perceptible sign of magnetism could be noticed; but on sending round it a current of fifty Grove's cells, each platina of which exposed a surface of twenty-four square inches, highly charged, no mechanical force that we could command would separate the keeper from the magnet. Two hundredweight of iron nails, each nail being six inches long, were attracted with such force, that it required great effort to pull one from the poles of the electro-magnet. Its inductive power was also enormous, as the balance-wheel of many a watch, unfortunately, informed its possessor, who ventured too close to the electro-magnet when the current of the battery was passing.

It will be premature for us here to enter into a full discussion of the laws of electro-magnetic induction, which will be reserved for our future pages, when we take up an inquiry of the law of electro-magnetic phenomena.

It may be naturally supposed, from the remarks, experiments, &c., that have been previously suggested, that magnetism must be something in the shape of a communicable fluid, because the same expressions are used in regard to what is popularly termed the "electric fluid." But here we must caution our readers from confounding *phrase* with *fact*. What we know of the real nature of magnetism and electricity amounts to nothing. All our theories on such matters are pure guesses. We cannot interpret how such forces of nature act, simply because our knowledge of their phenomena is limited. Analogy points out many points of resemblance between all the forces that act on matter; but we have yet to wait for that generalising mind that, placing before us each fact, can combine, in one theory, the essential cause.

TERRESTRIAL MAGNETISM.

It is evident, from what has been previously stated, that all the magnetic phenomena we observe must arise from causes inherent to the earth, or, perhaps, more properly, our globe. We have seen that a piece of steel can be so influenced as to have a polar direction; that is, it points, if properly magnetised, nearly north and south, subject to variations, with which we shall have hereafter more particularly to deal. We cannot, therefore, but suppose that there must reside in our globe an influence that causes the effects to which we are now about to draw particular attention; and this will become a matter of certainty as we proceed.

As Sir David Brewster justly observes—"Not only is a magnetised body directed in this manner by some unseen power, an unmagnetised body, such as a piece of iron, may be rendered permanently magnetic by the same power. This phenomenon is said to have been first observed in the vertical [perpendicular] rod of the weathercock of the church of the Augustines at Mantua, though others have ascribed the discovery to Gassendi. This rod had become magnetised by the continued action of the power of which we speak. In later times, it has been observed that a bar of soft iron is, by the influence of the same power, converted into a temporary magnet, with a north and south pole, when it is placed in the direction which a magnetic needle assumes, and is inclined to the horizon.

"If, in place of suspending the needle, or making it move horizontally on a pivot, we take an unmagnetised needle, and balance it upon a horizontal axis, then it will, of course, lie horizontally; but if we magnetise the needle, we shall find that it no longer remains horizontal, but takes an inclined position, or *dip*, as it is called.

"If we take a magnetic needle, and suspend it by a silk fibre, we shall find that, when it is pushed out of its position of rest, it will perform a certain number of oscillations in a given time before it again takes a fixed position. When this observation is made in different latitudes, it is found that the needle is brought to rest

sooner in some places than in others; which proves that the intensity or strength of the magnetic force which directs the needle, varies in different latitudes. Hence we have to consider three important classes of phenomena in reference to terrestrial magnetism; namely—

"1. The variation or declination of the needle, and its laws.

"2. The dip or inclination.

"3. The intensity of terrestrial magnetism."

In such terms Sir David Brewster enunciates the phenomena that characterise terrestrial magnetism; and each class of them is highly important, not only in a scientific point of view, but especially as bearing on the use, regulation, &c., of the mariner's compass.

The ancients, although they were acquainted with the attractive powers of the magnet, were ignorant of its directive or polar qualities; hence, of course, the early navigators were compelled to perform coasting voyages; for frequently the heavens would be so obscured by cloud, that the position of the fixed stars could not be observed. There is no doubt, however, that the Chinese employed the magnetic needle, as a guide to travelling on land, long before our era—some say a thousand years; and they had also discovered the variation of the needle four centuries before Columbus. In respect to Europe, we have no certain account of the use of the needle before the commencement of the twelfth century.

Columbus first noticed the variation of the needle in 1492; but it had been discovered before then, although that eminent navigator was not aware of it, and consequently its discovery has been ascribed to him. But it was at a much more modern date before instruments of sufficient delicacy were employed to obtain anything like well-defined and accurate results. Brewster remarks—

"The first person who attempted to collect and generalise the immense number of observations which had been made in the variation of the needle, was Dr. Halley, who published them in a sea-chart in 1700, in which he traced lines through all parts of the globe, where the variation was 0°, 5°, 10°, &c. These lines, which have since been called Halleyan lines or curves, excited great interest, and had the advantage of giving, at once glance, an ocular picture of the phenomena in every part of the world. As this *variation chart*, however, soon got old, from the rapid changes in the variation, as well as from confused methods of observation, Messrs. Mountain and Dodson collected, from the records of the Admiralty, and from the papers of various naval officers, about 50,000, which they laid down in variation charts for 1745 and 1756.

"The next step in the generalisation of the phenomena of variation, was made by Mr. Churchman, who published, in 1794, a programme of a *Magnetic Atlas*. He refers his variation lines to two poles, one of which he placed, for the year 1800, in latitude 58° north, and longitude 134° west of Greenwich, very near Cape Fairweather; while the other pole was in latitude 58° south, and longitude 165° east of Greenwich. He supposed the northern pole to revolve in 1,096 years, and the southern one in 2,289 years.

"It is to Professor Hansteen, however, that we are indebted for the most satisfactory collection of observations on the variation of the needle, and for the most philosophical generalisation of them. In the Magnetic Atlas, which accompanies his work on the magnetism of the earth, he published a variation chart for 1787, in which the irregularities and inflexions of the curves, and their total want of symmetry, prove how irregular are the causes on which terrestrial magnetism depends. In this chart, the *western line of no variation*, or that which passes through all the places on the globe where the needle points to the true north, begins in latitude 60°, to the west of Hudson Bay, proceeds in a south-east direction through the North American lakes, passes the Antilles and Cape St. Roque, till it reaches the South Atlantic Ocean, where it cuts the meridian of Greenwich in about 65° of south latitude. This line of no variation is extremely regular, being almost straight till it bends round the eastern part of South America a little south of the equator. The *eastern line of no variation* is exceedingly irregular, being full of loops and inflexions of the most extraordinary kind, indicating the action of local magnetic forces. It begins in latitude 60° south, below Australia, crosses that island through its centre, extends through the Indian archipelago with a double sinuosity, so as to cross the equator three times, first passing north of it, to the east of Borneo, then returning to it and passing south between Sumatra and Borneo, and then crossing it again beneath Ceylon, from which it passes to the east through the Yellow Sea. It then stretches along the coast of China, making a semicircular sweep to the west till it reaches the latitude of 71°, where it descends again to the south, and returns northwards with a great semicircular bend, which terminates in the White Sea. These lines of no variation are accompanied through all their windings by other lines where the variation is 5°, 10°, 15°, &c., these last lines becoming more irregular as they recede from those of no variation. In the South Pacific Ocean, and the equatorial part of the North Pacific, they are so little dependent on the lines of no variation, that they form returning curves of an elongated oval form, the curves of 2°, 3°, 4°, 5°, 6°, and 7°, crossing the equator and the tropic of Capricorn twice, so that in the centre or axis of the ovals which these lines form, there should be a fragment of a line of no variation.

"The great changes which have taken place in the variation subsequent to 1787, and the number of new observations which had been made in every part of the world, induced the late Mr. Barlow, in 1833, to construct a new variation chart. * * * * In the charts, both of Hansteen and Barlow, the variation lines exhibit a convergency at their extremities; and Hansteen considered that it proved that there are four points of convergency, two in each hemisphere, a weaker and a stronger, on oppo-

site sides of the poles of revolution. These four points he considered as the *four magnetic poles* of the globe; and, by comparing observations which have been made at different times, he concluded that they have a regular motion round the globe, the two northern ones from west to east, in an oblique direction, and the two southern ones from east to west, also obliquely. The following are the periods of revolution, as calculated from the best observations previous to 1817.

The *strongest* NORTH pole in 1,740 years.
The *strongest* SOUTH pole in 4,609 years.
The *weakest* NORTH pole in 860 years.
The *weakest* SOUTH pole in 1,304 years.

"Hansteen considered the four poles as originating in two magnetic axes, the two strongest being the termination of one axis, and the two weakest of the other; and he conceives that they may have been produced either along with the earth itself, or at a later epoch. According to the first supposition, it is not easy to account for their change of position; but, according to the last, they must have originated either from the earth alone, or from some external cause. If they originated in the earth, their change of position is still unsusceptible of explanation; and hence Hansteen conceives that they have their origin from the action of the sun heating and illuminating the earth, and producing a magnetic tension as it produces electrical phenomena."

The same philosopher remarks, that "the four periods above mentioned become, by a slight alteration, 864, 1,246, 1,728, and 4,320;" and he adds, rather fancifully for a man of science, that "these numbers are equal to 2 × 432, 3 × 432, 4 × 432, and 10 × 432; and that the number 432 is one of the most important among the sacred numbers of the Indians, Babylonians, Greeks, and Egyptians, which are said to depend on certain combinations of natural events. According to the mythology of the Brahmins, the duration of the world is divided into four periods: the first of which is 432,000 years; the second twice that period; the third, and so in all $(1 + 2 + 3 + 4) = 10 \times 432{,}000$ years." But, becoming practical, he adds, "the shortest line in which all the four poles can accomplish a cycle, and return to the same state as at present, coincides exactly with the period in which the precession of the equinoxes will amount to a complete circle, reckoning the precession at a degree in seventy-two years."

It would be impossible for us to give, in this work, even an abstract of the thousands of observations that have been made during the last hundred years in various parts of the world. The great scientific and practical interest that is connected with the subject, led to the establishment of magnetic observatories in all parts of the world; and, consequently, the amount of knowledge thus accumulated has been enormous, and has led to very much more definite ideas as to the cause of magnetism, especially since the discovery of electro-magnetism and thermo-electric currents. But this is a subject with which we shall have more fully to deal presently.

The following table gives the variations for London for nearly 300 years:—

Table of the Variation at London, from 1576 *to* 1864.

Year.	Variation.	Direction, East or West.
1576	11° 15′	east.
1580	11 17	east maximum.
1622	6 12	east.
1634	4 5	do.
*1657 } 1662 }	0 0	no variation.
1666	0 34	west.
1670	2 6	do.
1672	2 30	do.
1700	9 40	do.
1720	13 0	do.
1740	16 10	do.
1760	19 30	do.
1778	22 11	do.
1790	23 39	do.
1800	24 36	do.
1813	24 20 17″	do.
1815	24 27 18	maximum west.
1816	24 17 9	west.
1820	24 11 7	do.
1831	24 0 3	do.
1864	21 15 0	do.

In the year 1878 the variation at Greenwich was 18° 50′ W.; and in 1882 it amounted to 18° 20′ W.

Of course the variation at identical periods differs for various places, according to the longitude and latitude; and, consequently, in respect to their position in reference to the magnetic meridian. It would be difficult to give a table showing the variation for various parts of the world at the same date; for the observations have been taken at so many periods, and only in certain cases simultaneously. Some idea, however, may be gained by the following illustrations:—

The year of no variation, at Paris, was 1669; whilst, at London, 1657 to 1662 was the period of no variation.

In the year 1800, the variation in Paris was 22° 12′, and, in London, 24° 36′; both westerly.

The maximum westerly variation occurred about the year 1814, at Paris, and was 22° 54′; whilst, in London, the maximum occurred in 1815, and was 24° 27′ 18″; both westerly.

The maximum variation at the Cape of Good Hope, westerly, occurred in 1791, and was 25° 40′.

At the periods generally above named, or since 1790, the variation of all places on the American continent was easterly, most of them being situated on the opposite side of the magnetic poles, compared with Europe. Sir David Brewster observes—

"Professor Hansteen explained these progressive changes in the variation of the needle by the motion of the four magnetic poles [already described in this page]. Taking the

* In these years the needle pointed directly true north and south.

variations at Paris for the northern hemisphere, he remarked that, in 1580, the weak north pole in Siberia was about 40° east of Greenwich, or to the north of the White Sea; while the strong American pole was about 136° west of Greenwich, or 36° east of Behring's Straits. The weak pole, therefore, lay nearer Europe than now, and the strong one more remote. Hence the action of the former predominated, and drew the needle eastward. But the weak pole now withdrew itself towards the Siberian ocean from Europe, and the strong one approached it. The action of the latter, therefore, predominated, and the needle turned westward till 1814, when it reached its greatest declination, and commenced its easterly course."

But besides the extended period already mentioned, as attended by variation of the needle, it has also yearly, daily, and even hourly variations. The latter—the diurnal—are now observed with the greatest precision, and registered by means of photography, by instruments of the most refined character. In respect to the annual variation, "during three months, between the vernal equinox and the summer solstice, the needle retrogrades to the east; and during the following nine months its general motion is towards the west."

The cause of the diurnal variations is evidently some solar influence, for the direction and intensity of them depend on the position of the sun, and the time of day. This interesting subject will come under notice when we describe the instruments that are employed to measure the diurnal variations. We may, however, just observe that many ingenious theories have been proposed to account for such phenomena. Brewster observes—"The sun is now universally allowed to be the cause of the diurnal variations of the needle. Canton ascribed them to the action of solar heat, having ascertained that heat tends to diminish the attractive power of the magnet, and assuming that the direction of the needle was due to the resultant of magnetic forces of the terrestrial sphere. When the sun was to the eastward of the needle, the forces lying to the east suffered a diminution of power, in consequence of which the westerly force prevailed, and the north end deviated to the west. When the sun, on the other hand, was to the westward of the needle, the power on that side diminished, and the needle returned again to the eastward."

Now thermo-electricity is explanatory of earth electrical currents, and may be considered as the cause of the diurnal variation; but, for reasons already stated, it will be premature for us to enter into that question; because, to understand the reasoning that supports the views held, a knowledge of the laws of electro-magnetism must first be possessed. It is remarkable, that the motion of the spots on the sun, the diurnal variation of the magnetic needle, and the rise and fall of the barometer, with the daily apparent motion of the sun, are all, by some mysterious power, connected together.

A reflection on these fscts is of the deepest interest, as showing, so far as we can now see, a oneness of origin of many of the forces of nature. As we progress in our investigations of natural phenomena, our details, experiments, observations, and calculations become so intricate as to require the greatest exertion of our intelligence to arrive at a conclusion that satisfies all the conditions of the case. But that conclusion once arrived at, discloses a simplicity that, in itself, eclipses the wonder of the phenomena themselves. How many weary and laborious years did it require to form the theory and laws of gravitation? But these, once discovered, gave us a key to all planetary motion, and opened out to us a view of the laws of nature generally, and of the planetary system, that exceeds our power of description. Grand as may be that view, still it may, some day, be surpassed by a further acquired knowledge of the cause of magnetic phenomena. The philosopher, utterly separated in appearance from external nature, measures the length of a pendulum, and counts the number of its vibrations, and thus can study and measure gravitative force. To him unacquainted with experimental philosophy, it would seem transcendent beyond human power, that by such and similar means the physicist should be enabled to weigh the stars as in a balance. Again, he magnetises a needle, counts its oscillations, and measures the intensity of another force—magnetism—with great precision. If, at a distance of 91,000,000 of miles, the solar atmosphere is disturbed with magnetic storms; if, nearer the surface of the earth, and but a short distance from us in our atmosphere, similar disturbances take place; or if, on the crust of the earth, the magnetic and electrical influences are moved to increased action—a little needle indicates and measures such phenomena, and, unknown to the world at large, the philosopher holds communication with the omnipotence of the Creator, and is led, with awe and wonder, from Nature to Nature's Maker.

Here we may briefly notice a peculiar form of magnetic disturbance in respect to variation, caused, apparently, by the aurora borealis, that has just been hinted at. We remark, *apparently* by the aurora borealis, because the latter may be only a sign, and not a cause of the phenomena. Hansteen maintained "that the extraordinary shivering movements of the needle are, perhaps, never exhibited except when the aurora is visible; and that this disturbance seems to operate at the same time in places the most widely separated. The extent of these movements may, in less than twenty-four hours, amount to five or five and a-half degrees. In such cases, he adds, the disturbance is also communicated to the dipping-needle; *and as soon as the crown of the aurora quits the usual place (the points where the dipping-needle produced would meet the sky), that instrument moves several degrees forward*, and seems to follow it. After such disorders, he continues, the mean variation of the needle is wont to change, and not to recover its previous magnitude till after a new and similar disturbance. During the continuance of the aurora borealis, the intensity of the earth's magnetic force seems to grow weaker; for which

reason the needle recedes from that magnetic pole where the ray of the aurora is displayed.

"The influence of the aurora borealis on the needle has been studied with particular care by M. Arago, whose accurate and regularly continued series of observations on the daily changes of the magnetic needle at Paris, has enabled him to compare these changes with the occurrence of the northern lights. The following is an abstract of his views on the subject :—The appearance of an aurora causes the magnetic needle to vary several degrees to the east and west of its mean position. In the region where it appears, luminous beams, differently coloured, shoot from all points of the horizon ; *and the part of the heavens where all these beams or radiations unite, is precisely that to which a magnetic needle directs itself when suspended by its centre of gravity.* M. Arago has also shown that the concentric circles, which show themselves almost always before the luminous beams, rest each upon the two points of the horizon equally distant from the magnetic meridian, *and that the most elevated points of each arch are exactly in this meridian.* From these two facts he concludes that there is a relation between the causes of the aurora borealis and the motions of the magnetic needle ; and, from observations made in places remote from each other, he infers that the aurora acts even before it shows itself in the horizon, and that its influence is exerted at very considerable distances. In a subsequent paper on the subject, M. Arago shows that the auroras which are visible only in America, at St. Petersburg, and in Siberia, in spite of the immense distance which separates us from these regions, produce a perceptible derangement of the magnetic needle at Paris. M. Arago at first believed that even the auroras of the southern hemisphere extended their influence to Paris ; but he has since found, that on the days when these southern auroræ took place, the phenomenon was observed also in the north ; so that no conclusion can be properly deduced from this coincidence with the observed derangements of the needle."

As a rule, all arctic voyagers maintain that the appearance of an aurora is accompanied with a disturbance of the magnetic needle ; but this is, perhaps, not always resulting from the aurora. In November, 1867, for example, during the terrific storm at St. Thomas and the island of Tortola, in the West Indies, the compasses of most of the vessels that were lost in the few hours that the storm lasted, were rendered absolutely useless by the great amount of free electricity then in the atmosphere. We have now before us the report rendered by Captain Vesey, the senior officer on the station, giving particulars of this astonishing occurrence, dated St. Thomas, November 2nd, 1867.

A theory was propagated to account for the fact that some aurora do not affect the needle, by Sir David Brewster. In his *Treatise on Magnetism*, he remarks—"We cannot adopt the opinion of Mr. Christie, that *every aurora must disturb the magnetic needle*; and we admit only the observed fact, that there are auroras which disturb, and auroras that do not disturb the needle.

"In order to explain more fully our views on this subject, let us suppose our magnetic atmosphere to be undisturbed by any cause, and that the needle in every magnetic meridian rests in a state of perfect equilibrium in its mean position. Let us now suppose that the magnetic atmosphere is disturbed in east longitude 90° and latitude 0°, either by a change of temperature, or by electric action, or by any cause which displaces the magnetic matter from that meridian, or accumulates it there. Such a change must necessarily affect the horizontal magnetic needle in all places to the east and west of it ; but it will not affect the horizontal needle in the meridian where it takes place, or in the opposite meridian, as the resultant of the magnetic forces, though they may be changed in intensity, will not be changed in direction. In like manner, if various discharges take place simultaneously or successively, there will be certain places where the direction of the resultant forces is not changed, and other places where the change of direction is a maximum. An universally suspended needle, however, will have its direction always changed, unless when the disturbing cause is in the direction of its axis. Hence, then, it is easy to understand (nay, the fact is a necessary result of our hypothesis) why there are auroras which disturb and auroras which do not disturb the needle ; why distant auroras affect it when nearer ones do not ; and why the needle is in a shivering or constantly oscillating state during auroras in which the places where the magnetic atmosphere is disturbed are constantly changing. In the same manner, we may account for the influence on the needle, observed by Sir Everard Home and Captain Back, during the prevalence of a thunder-storm, while the electricity of the atmosphere destroys by its action the magnetic equilibrium, when this action is not compensated by an equal one on the opposite side of the magnetic meridian. When such a compensation takes place, the needle will not deviate from its mean position, though the number of its vibrations in a given time may be altered."

We may here state that the aurora borealis has a most disturbing effect on the electric telegraph when the wires are underground.

The Mariner's Compass.—This invaluable instrument, that really was the founder of all the commercial success of civilisation, has a great variety of forms, according to the purposes for which it is required ; but as such, so far as magnetism is concerned, are matters of purely technical interest, it will be unnecessary for us to enter into their description. This would only be understood by the navigator, who will have either sufficient knowledge himself to guide him to a right choice, or can obtain the necessary description from the instrument-maker of whom he may purchase the article.

It is almost unnecessary to remark that the compass is a special application of a horizontal magnetised piece of bar steel, the value of which depends on its polar power ; that is, of pointing

in the direction of north. It does not matter if it vary from that; for, as previously shown, we can, by certain calculations founded on long observation, make all necessary allowances for such variation, whatever periodic nature or amount they may take.

The ordinary form of the mariner's compass is that of a magnetised steel bar, so mounted that it may be free to move horizontally in every direction. The dip, of which we shall have more particularly to speak hereafter, is corrected by balancing the "needle," or bar, so that, when the latter is at rest, it shall be completely horizontal. It is evident, however, that an instrument of the kind on ship-board, as the vessel moves, would be inclined with it; consequently, various mechanical arrangements are adopted, so that the needle, no matter in what position the ship may move, shall be invariably horizontal. This is effected by a combination of joints, which, together, will act in such a manner that the compass-needle is always horizontal. Of recent years, suspension in fluids has been successfully substituted for the mechanical arrangements, which, unless kept well cleansed and oiled, soon get stiff, owing to the action of the salts of the sea-water spray.

Over the needle is a card, marked with all the points of the compass. First are the four cardinal points of north, south, east, and west. These are each sub-divided into eight other points, the names of which will be easily recognised by the initial letters in the cut (Fig. 194). Hence

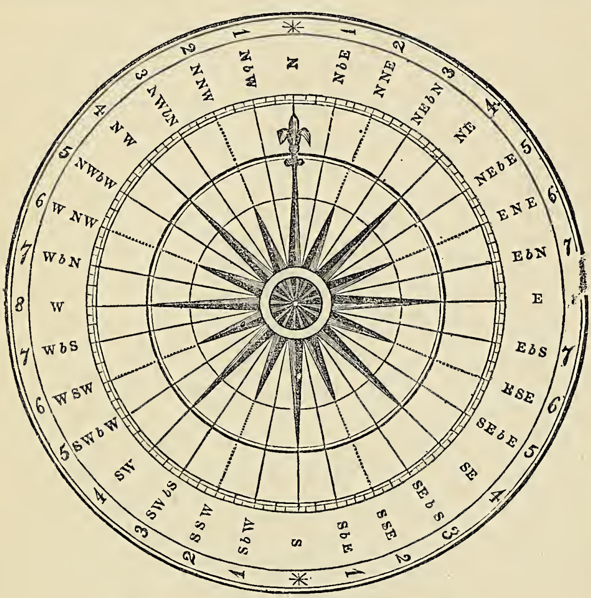


Fig. 194.—The Mariner's Compass.

there are thirty-two points; and, as a circle is divided into 360 degrees, it follows that each "point" must consist of 11° 15′, or eleven degrees and fifteen minutes.

The proportion which each point and quarter point occupies, or the angles which the different points make with the horizon, are shown in the following table:—

Table of the Points of the Compass.

North.		Points.	Angles.	South.	
		¼	2° 49′		
		½	5° 37½′		
		¾	8° 26′		
N. *b.* E.	N. *b.* W.	1	11° 15′	S. *b.* E.	S. *b.* W.
		1¼	14° 4′		
		1½	16° 52½′		
		1¾	19° 41′		
N. N.E.	N. N.W.	2	22° 30′	S. S.E.	S. S. W.
		2¼	25° 19′		
		2½	28° 7½′		
		2¾	30° 56′		
N.E. *b.* N.	N.W. *b.* N.	3	33° 45′	S.E. *b.* S.	S.W. *b.* S.
		3¼	36° 34′		
		3½	39° 22½′		
		3¾	42° 11′		
N.E.	N.W.	4	45° 0′	S.E.	S.W.
		4¼	47° 49′		
		4½	50° 37½′		
		4¾	53° 26′		
N.E. *b.* E.	N.W. *b.* W.	5	56° 15′	S.E. *b.* E.	S.W. *b.* W
		5¼	59° 4′		
		5½	61° 52½′		
		5¾	64° 41′		
E.N.E.	W. N.W.	6	67° 30′	E. S.E.	W. S.W.
		6¼	70° 19′		
		6½	73° 7½′		
		6¾	75° 56′		
E. *b.* N.	W. *b.* N.	7	78° 45′	E. *b.* S.	W. *b.* S.
		7¼	81° 34′		
		7½	84° 22½′		
		7¾	87° 11′		
E.	W.	8	90° 0′	E.	W.

The angles in the above table nowhere differ from the truth by more than a quarter of a minute in the measurement of the arc of a circle. *Boxing the compass*, a well-known nautical phrase, consists in being able to repeat correctly each of the points in their proper order, as shown in the preceding cut (Fig. 194).

Of course, in steering, the vessel is supposed to proceed in a line carried through the centre of the compass-card, and parallel to the axis of the ship when the latter is horizontal. Thus, supposing the ship be steered due north, then a line supposed to be drawn across the compass-card, from the stern to the bows of the vessel, would also point due north; and so on for each other direction on the card. Presuming that the mariner's compass be at first perfectly constructed, and that what has been already stated in respect to periodic, local, and other such general known variations be attended to, it might, at first, be naturally supposed that the compass is an instrument which might be implicitly trusted as a guide night and day, in storm and tempest, and, in fact, in all circumstances. But, practically, such is not the case, for many reasons that may be briefly noticed, together with the remedies that have been suggested to overcome such difficulties.

In the first place, as already stated, the mode of building iron vessels tends to induce in

them a certain amount of magnetism; and so much does this inductive influence of terrestrial magnetism thus act, as to render the vessel a complete artificial magnet. One of the most remarkable instances of this on record was that of H.M.S. *Northumberland*, launched in 1866. The magnetism of this vessel was so great, that the indications of the compasses on board were valueless. An ingenious method of getting over this difficulty was suggested. It was that of encircling a portion of the vessel with covered wire, through which a voltaic current was passed, so as to reverse the magnetic polarity of the vessel, and, consequently, to destroy that polarity by inducing an opposite condition.

At the British Association meeting of 1866, Mr. E. Hopkins made the following remarks in respect to the—

"'Depolarisation of Iron Ships, to prevent the Deviation of the Compass.'—The great importance of the subject induced the Lords of the Admiralty to place the *Northumberland* under the direction of the author, to test the practicability of his new system of depolarising ironclads. The magnetical conditions of the *Northumberland* were carefully surveyed, and the ship was found to be a very powerful magnet—the bow being the north pole, and the stern a south pole. The radiating polar lines extended from the bow and stern respectively to the distance of sixty feet, within which limits the compasses were necessarily under the control of the magnetism of the ship. After she had been launched, the ship was taken to the Victoria Docks, and placed in a contrary position to that which she occupied when on the slip. The ship's magnetic and polar conditions were again carefully surveyed. On the 4th of August the ship was depolarised, by means of two Grove's batteries, of five cells each, and electro-magnets, in a few hours. This experiment proved at once that the polarity acquired by an iron ship in building can be destroyed before leaving the dock; indeed, the result could not be otherwise, as it is merely applying a well-established principle to a new purpose. Magnets can be polarised and depolarised at pleasure, whatever their magnitude. A compass may now be carried round the *Northumberland* within four feet of the plates without being appreciably affected. Hence there can be no just excuse, in future, for allowing iron ships to be so much exposed to dangers owing to the errors of compasses, arising from the acquired magnetism in building, or from the disturbance of any masses of iron on board."

But if a ship be built entirely of wood, the masses of iron, in the form of chains, anchors, portions of the cargo, and other articles, may all largely tend to derange the compasses, and to produce the greatest danger to the navigator. The instances in which this has caused serious loss of life and property are so numerous, that we can scarcely select one that exceeds the other in the serious results that have been occasioned. The stranding of the *Great Britain* in Dundrum Bay, off the Irish coast, some years ago, will be in the remembrance of many of our readers, as one of the most remarkable instances on record. At certain times the deviation thus caused is very great. On one occasion, whilst sailing in a dense fog, between Ayr and Campbelton, in the west of Scotland, we noticed a deviation of upwards of 100°; for on the fog clearing off, the sun was setting, according to the indications of the compass, in the north-east, in place of somewhat south of westward, which was the true position. Sir D. Brewster remarks—

"Mr. Wales, the astronomer to Captain Cook's expedition of discovery, first discovered the fact that such a deviation existed; but he does not seem to have suspected its cause. Mr. Downie, master of his majesty's ship *Glory*, was the first person who pointed out the true origin of the deviation. 'I am convinced,' says he, 'that the quantity and vicinity of iron in most ships [no iron vessels then existed] have an effect in attracting the needles; for it is found, by experience, that the needle will not always point in the same direction when placed in different parts of the ship. Also, it is rarely found that two ships, steering in the same course by their respective compasses, will go exactly parallel to each other; yet these compasses, when compared on board the same ship, will agree exactly.'

"In his survey of the coast of New Holland [Australia], in 1801 and 1802, Captain Flinders observed great differences in the direction of the needle, which arose only from change in the direction of the ship's head, the direction being westerly when the ship's head was to the east, and *vice versâ*. Hence he concludes that the attractive powers of the different bodies in the ship, which are capable of affecting the compass, are collected into something like a focal point or centre of gravity, and that this point is nearly in the centre of the ship, where the shot is deposited, for here the greatest quantity of iron is collected together. He likewise supposed that this magnetic centre is of the same name as the pole of the hemisphere where the ship is; and, consequently, that in New South Wales, the south end of the needle would be attracted by it, and the north end repelled. From this hypothesis, he concludes that the phenomena must be exactly reverse to the northern hemisphere:" that is, in respect to the inductive action of terrestrial magnetism on the iron in or of the vessel.

The subject was immediately after taken up, and investigated, by some of the chief navigators and scientific men of the day, including Barlow, Sabine, Scoresby, and many of the arctic navigators, as Ross, Parry, &c.; and, to the present time, it has been a subject of careful investigation, that has led to a variety of schemes, the leading principle of which is to ascertain the amount of magnetism in or of a ship that deranges the needle, and to overcome the influence by plates of iron or magnets placed near the needle; the attractive influence thus being brought to bear on it, neutralising that of the ship, and so leaving the needle unaffected.

Before leaving a port, the compasses of the vessel are carefully adjusted by such means. The ship is removed to calm water, where she

will swing round with the tide. "An observer, with a needle and theodolite, is placed at some distance from the shore, from which he can perceive the ship while it is turning its head in different directions : the compass on board the ship is under the management of another observer, with similar apparatus. At a given signal, the observer determines the angle which his own needle makes with the axis of the telescope (one being directed to the other), which is called the central line. But as the needle on shore experiences no disturbing action, it is evident that if the needle on ship-board also experiences none, the two needles will be parallel, and will form the same angle with the central line. Hence the difference between these two angles, when they are not the same, is that which is produced by the magnetic action of the iron in [or of] the vessel upon its compass-needle at the instant of observation. Let the vessel be now made to turn round completely, and let a new observation be made at every azimuth of ten or twelve degrees, and we shall then have the value of the deviation produced in all positions of the ship's head upon the compass-needle." The compass of the ship, as that of the shore, are then made to change places. The compensator's effect is then observed in the ship's compass, which is placed on a box, and gradually turned round on an axis, to ascertain the effect of the compensator at different azimuths. The position of the compensator is then adjusted so that it shall produce the same amount of deviation that was caused by the iron of the ship. The compass is then restored to the vessel, placed in its proper position, and the compensator is finally adjusted so as to fulfil accurately a neutralising effect on the inductive action, on the compass-needle, of the cargo, hull, &c., of the vessel.

We are indebted to the late Professor Barlow for having first suggested this ingenious and philosophical method of adjusting ships' compasses, and so of neutralising the deviation caused by cargo, &c. Many modifications of this method have been adopted ; but as they are chiefly of interest to the navigator alone, we need not enter into their discussion.

None but those who have been in circumstances of peril from the irregular action of the compass, can imagine the intense anxiety that the navigator suffers in such circumstances. Some years ago, off the east coast of England, we spent the whole night on deck with the commander of an iron steam-vessel, under such circumstances. There were three compasses on board, but they all varied. The sea was as calm as a pond, and consequently there was no motion of the vessel to cause the vibration of the needle, which is essential to make it "work" well ; that is, readily move on its pivot. Added to all other difficulties, a dense fog had prevailed for eighteen hours ; and we had, in the previous morning, been nearly sunk by collision with a large steamer. This occurrence, of course, had caused an increase of anxiety to all on board. It is considered by some that fog greatly impedes the action of the compass, whilst others do not believe in the effect. However, in this instance, as soon as the fog cleared off, the compasses worked well, and we noticed the same result in the voyage from Ayr, already formerly mentioned.

On the question of the effect of fog, we have previously shared the opinion that it was imaginary ; but having seen the effect in the occurrences just described ; remembering, also, that in the experiments of Mr. Crosse, he found frequently a greater amount of free electricity in the air during a fog than even in a thunder-storm, and, lastly, from reading the effects of electricity on the compasses of the ships destroyed during an earthquake at St. Thomas and Tortola, (already mentioned at p. 347, *ante*), it would seem that a fog may, and perhaps does, affect the working of the needle.

Carelessness, shifting of the cargo, unloading it at different ports during the voyage, especially if it be iron, and many other circumstances, tend to diminish or destroy the utility of adjusted compasses, or rather, of the compensator, first fixed, to overcome the attraction of the cargo and vessel. In respect to the first cause, carelessness, it is evident that if masses of iron are brought near the compass, they must, more or less, affect the needle, and destroy the value of the compensator. On one occasion we remember a vessel being steered by the compass for more than an hour in a wrong direction, simply owing to the cabin-boy having stupidly placed a box of dinner knives, that he had been cleaning, close to the compass-box ! Owing to this the vessel took a direction several miles north to that intended ; and had this occurred at night, there is little doubt that many lives and much property would have been sacrificed. A vessel on a voyage from here, say to India, Australia, or China, will most probably have to deliver portions of her cargo at various ports. If that be iron, of course the compensator will cease to give true results ; because, as the iron in the vessel is lessened, the action of the compensator on the needle will be increased. These, and many other circumstances that we need not enter into, seriously affect the compass as the guide of the mariner, and require an intelligent supervision of the commander.

We next turn to consider the—

Dip of the Needle.

It has already been noticed, that however truly a piece of steel may have been balanced, it will, on being magnetised, dip or incline out of the perpendicular towards the earth, at various angles at different parts of the earth's surface. This is due to the attractive influence of the earth's magnetism ; for at the magnetic poles the dip is 90°, the needle then taking a complete vertical position with the horizon ; whilst at certain other positions, as seen at the equator, but more correctly at 90° from a magnetic pole, there will be no dip, the needle maintaining a horizontal position.

It is evident that, as the magnetic poles are not coincident with the poles of the axis of the earth, so the magnetic equator cannot be coin-

cident with the terrestrial equator. It would be tedious to enter into the extended observations which have been made to find the nodes of intersection of the two equators; that is, those points in which the lines marking the equators touch each other. From a variety of data, it was concluded "that the magnetic equator will meet the equinoctial line only in two points, which are diametrically opposite; the one being situated in the Atlantic Ocean, and the other in the Great Ocean, nearly in the plane of the meridian of Paris. When this equator meets only some scattered islands, it recedes only a little from the equinoctial line. When the islands are more numerous, it recedes farther; and it reaches the maximum deviation in both hemispheres only in the two great continents it traverses. The American magnetic pole was fixed by Ross in north latitude 70° 5′ 17″, and in west longitude 96° 45′ 48″.

It will hence be apparent that the dip of the needle must vary in all parts of the globe, being nothing on the magnetic equator, and at a maximum over the magnetic pole, when it will be completely vertical.

For precisely the same reason that causes a *variation* of the magnetic variation (already so fully entered into at p. 344, *et seq.*), a progressive change takes place in the angle of the dip. At p. 345, *ante*, will be found a table giving the different variations of the needle, for the last two or three hundred years, at London.

Table of the Changes in the Dipping-Needle's Inclination at London.

Year.	Amount of Dip.
1720	74° 42′
1773	72 19
1780	72 8
1790	71 53
1800	70 35
1818	70 34
1821	70 3
1828	69 47
1830	69 38
1864 (at Kew)	68 12
1878 (Greenwich)	67 38
1882 ,,	67 32

Just as the variation differs progressively and locally, so does the dip. In the years 1821-'22, the dip of the needle at Paris was 68° 12′, or exactly that of London (Kew) in 1864. In that year, the dip at Lisbon was 60° 19′, or about 8° less than that of London.

The dip undergoes, like the variation of the needle, other periodic changes; being greater in winter than in summer: also, daily, the dip is greater in the forenoon than after the sun has passed the meridian of any place.

Intensity of Magnetism.

The determination of the amount of force exercised by terrestrial magnetism is, in the methods adopted, similar to those used for measuring the force of gravitation on the surface of the earth.

It will be evident, in respect to the latter force, that the further the observer is removed from the centre of the earth, the less will the force of gravity act on any instruments he may employ to measure it. Consequently, any object that can be attracted to the earth, may be employed to measure the variation of gravitative power. The most convenient instrument that can so be employed is the pendulum. The weight, or bob, when moved out of the perpendicular, instantly tends to fall towards the earth, but is prevented from doing so by being suspended from a pivot. If mechanical force be applied, so as to keep up the vibration of the pendulum, the number of the vibrations made in any definite period of time, will show what the force of gravity is in any particular place. If a standard place be chosen, then any other nearer the equator will show less gravitative force; because, in proceding towards the equator, we increase our distance from the centre of the earth—the latter being twenty-six miles wider at the equator than at the poles. On the other hand, if we proceed toward the poles from the place of standard observation, then the gravitative force will apparently increase, because at each step we get nearer to the centre of the earth. This will be more readily understood by the following observations explanatory of the fact.

It is found that a pendulum having the length of 39·1393 inches, performs exactly one vibration in a second of time. If the same pendulum be taken to Paris, it will require *more* than a second of time to make that vibration, because Paris is further from the centre of the earth than is London. But if the same pendulum be taken to Spitzbergen, which is only about 11° from the pole, it will require a much shorter space of time to produce the vibration than a second of time, because at that place it will be several miles nearer the centre of the earth than when vibrating in London or Paris, and consequently the gravitative force, as just shown, is much greater.

By thus oscillating a pendulum in different latitudes, we can learn what the force of gravity is on various points of the surface of the earth, and, experimentally, the following results have been arrived at:—

Force of Gravity.

In the latitude of the Equator	32·0881
,, ,, Paris . . .	32·1820
,, ,, London . .	32·1908
,, ,, Spitzbergen	38·2526

The figures indicate the velocity of a falling body in a vacuum, per feet, at the end of the fall, in one second.

Now in a similar manner is the intensity of terrestrial magnetism measured. "The method of determining this important element by the number of oscillations of the needle, was first suggested by Graham, and brought to perfection by Coulomb, Humboldt, and others. If a needle whose axis of suspension passes through its centre of gravity, and which has its north and

south polar magnetism equal and similarly distributed, be made to vibrate by turning it from its position, and allowing it to return to that position by a series of oscillations, it is obvious that the earth's magnetism acts with equal force on each half, and that both these forces tend to draw the needle into the magnetic meridian. The greater the magnetic force, the more quickly will the needle oscillate and recover its primitive position [or come to rest. The needle is, in short, in the same circumstances as a pendulum oscillating by the action of gravity [as we have just explained] ; and, as in this case, the forces are as the squares of the number of oscillations made in the same time."

Here we must explain that all forces radiating from a centre, decrease in proportion to the square of the distance, and not in arithmetical proportion. Thus, if the force of gravity be 2 at any particular place, it will not be 1 at double that distance from the centre of the earth, but $\frac{1}{4}$th ; the square of 2 being 4, and $\frac{1}{4}$th the reciprocal of that number. The same law holds good in respect to heat and light, as may be readily proved, in the case of the latter, by measuring the area of a shadow produced by interposing an opaque object between a candle and a screen. Precisely the same rule holds good with magnetism ; hence why the *squares* of the times of oscillations are the relative or comparative measure of the force.

Again, quoting from Brewster—"Let us now suppose, to take the simplest case, that we make the dipping-needle oscillate in the plane of the magnetic meridian round the line of dip, and that when the experiment is performed at the equator, the number [of vibrations] in a second is 24, while in another place it is 25 ; then the intensities of the magnetic force at these places are as 25° to 24°, or as 625 to 576 ; or as 1·085 to 1·000. By carrying the same magnetic needle to various parts of the earth, the magnetic intensity at those places will be found from the number of its oscillations.

"In the application of this method, there are various practical difficulties, particularly the necessity of its resting upon knots, edges of steel, or agate, during oscillation, which do not exist if we make a needle oscillate horizontally when suspended by a fine fibre of silk. This latter method has, therefore, been the one universally employed, though a little calculation is necessary to obtain the intensity of terrestrial magnetism from the number of oscillations which are performed."

The limits imposed on us prevent our giving extended tables showing the varying intensities of different places on the globe. A table of this kind will be found in the *Encyclopædia Britannica*, by those of our readers desirous of still further investigating the subject.

We have already pointed out, at a previous page, that the amount of dip gradually increases from 0° at the equator to 90° at the magnetic pole, and it consequently results that the intensity of terrestrial magnetism must also increase in the same way.

According to a table given in the work above referred to, the increment of intensity, in respect to the dip, is as follows :—

Dip of the Needle.	Magnetic Intensity.
0°	1·0
25	1·1
45	1·2
64	1·3
73	1·4
$76\frac{2}{3}$	1·5
81	1·6
86	1·7

According to the determination in 1864, by careful observation, the mean magnetic force in English units was, at—

	Kew	10·3
	Lisbon	0·7
1878	Greenwich	3·90 B.A. units.
1882	,,	3·924 ,, ,,

A series of lines may be drawn on the map, showing places where an equal amount of magnetic force is found. These are called *isodynamic lines*, from two Greek words, signifying equal force ; and the discovery of them, during the last thirty years, has been an object of continuous observation with magneticians. These lines are nearly parallel to those of equal dip.

It will be evident, therefore, that these lines have the same relation to magnetic force that those of latitude have with gravitation, because, in both circumstances, the number of oscillations of either the needle or pendulum indicate the intensity of the respective forces.

The magnetic lines, however, have a peculiar curved form, very different to the circles of latitude. Roughly, we may compare their contour to an oval bent so that its two long sides are brought near to each other, resembling in form the figure 8. The curves thus formed are like lemniscates. The "intense" values of each of these sets of curves are distinguished by the number of oscillations performed by the needle at the place of observation.

The time of vibration of a magnet at Greenwich is 1·573 seconds ; and it became a question of interest as to what effect the removal of the needle above the earth might have in altering the number of vibrations. At first sight, it would seem certain that, if magnetic intensity was due to terrestrial causes alone, the further the needle was removed from the earth, the longer time would be required to effect a vibration, for precisely similar reasons to those that affect the vibration of the pendulum in respect to gravitation. The earliest magneticians, amongst whom were Humboldt and Kupffer, came to this conclusion.

In 1862, Mr. Glaisher, of Greenwich Observatory, and one of the most eminent of British meteorologists, undertook to make several balloon ascents at the instigation of the British Association, chiefly to determine the law of decrement of temperature due to height, and consequent diminution of atmospheric pressure, as indicated by the barometer. Incidentally, however, other subjects were included as matters of observation ; and, amongst them, the

question of the decrement of magnetic intensity with an increasing elevation above the earth.

Of course, a balloon is by no means a favourable arrangement for making magnetic observations, as the machine is constantly in motion, being, necessarily, lighter than the air in which it floats. Hence Mr. Glaisher obtained very indistinct results. He thus relates them in his Report for 1862—

Time of Vibration of a Magnet.

"On July 17th, at Wolverhampton, there were—

	s.		s.
30 vibrations of a magnet in	42·1;	that is, one vibration in	1·403
30 ,, ,,	42·5;	,, ,,	1·417
30 ,, ,,	42·4;	,, ,,	1·413

Therefore one vibration = 1·411 second.

"At the height of 18,844 feet one vibration = $1^s·489$.

"At the height of 20,244 feet one vibration = $1^s·536$.

"Therefore the time of vibration seemed to be somewhat longer.

"On July 30th, at the Royal Observatory, Greenwich, the time of the vibration of the magnet = 1·573 second.

"On July 30th, the mean of four sets of observations, at the mean height of 5,300 feet, gave—

One vibration = $1^s·572$,

being sensibly the same as the result on the same day as determined at the Observatory.

"On August 18th, at Wolverhampton—

	s.		s.
38 vibrations	= 60·0	∴ one vibration =	1·580
32 ,,	50·3	,, ,,	1·572
34 ,,	54·2	,, ,,	1·595
30 ,,	47·9	,, ,,	1·597
			4)6·344
Therefore one vibration = 1·586 second.			1·586

"At 11,000 feet 26 vibrations = 41·5 second.

Therefore one vibration = 1·590 second.

A result differing but little from that on the ground.

"August 20th, at the Royal Observatory, Greenwich, the time of one vibration was 1·580 second.

"August 20th, at the height of 3,800, one vibration = 1·583 second.

"On September 5th, I did not succeed in getting the time of vibration of the magnet at all in the balloon. During the ascent we were almost constantly going round and round—a motion fatal to observations of this nature; and failure, at all times, was the rule in these experiments. I commenced many series of experiments with the axis of the car in one position relative to the cardinal points of the compass, which I found to be different before the observations were completed; and, consequently, the observations were of no value.

"The general result of these experiments is, that the magnet vibrates in a somewhat longer interval of time at high elevations than on the earth. The number of experiments, however, is too few to speak decidedly on this point."

It thus seems that, apparently, the vibrations of the magnet diminish with increased distance from the earth; but the question still requires further observation to afford accurate results. If these could be obtained, they might prove exceedingly valuable to science; for it is more than probable that magnetic intensity, like the phenomena of variation and dip, is subject to increment and decrement at certain periods of the year and the day; respecting which, if space permit, we shall endeavour to notice more particularly.

Having thus drawn attention to the leading phenomena of terrestrial magnetism, we next proceed briefly to notice—

The Cause of Terrestrial Magnetism.

The question of the cause and nature of the magnetism of the earth cannot be disassociated from the theories of magnetism generally, electricity, electro-magnetism, and dia-magnetism. In respect to the theories of magnetism, it need scarcely be stated that their consideration lies at the basis of the question, and therefore it would be requisite to discuss them for the purpose of giving an exposition on the subject. But these are intimately connected with the phenomena of frictional and voltaic electricity; for, as we shall find when examining the phenomena usually embraced under the head of electro-magnetism, that electricity and magnetism are mutually producible. Another point also remains to be noticed: it is, that although, hitherto, we have only considered iron or steel as capable of exhibiting magnetic phenomena, we have restricted ourselves to a very narrow branch of the subject; for we shall find that *all* bodies in nature, whether liquid, gaseous, or solid, are affected variously and oppositely by magnetism under certain circumstances, such phenomena being usually embraced in what has been called *Dia-magnetism*.

From the great extent and variety of subjects connected, therefore, with magnetism, it is evident that we have much yet to learn before we can authoritatively say what the cause of terrestrial magnetism is. It will not, therefore, be a matter of surprise if we remark, that the various theories which have been offered to account for terrestrial magnetism, have been numerous, complex, and opposite in character.

Brewster remarks, that "The earliest and the most natural supposition is that of Dr. Gilbert—that the earth contains within itself a powerful magnet, lying in a position which nearly coincides with its axis of rotation. In this case the pole of this magnet, which acts in our northern hemisphere, must have south polar magnetism, as it attracts the north pole of the needle; while the pole in the southern hemisphere must have north polar magnetism, as it attracts the south pole of the needle. That this hypothesis would, generally speaking, represent the ordinary phenomena of terrestrial magnetism, may be easily shown by placing a bar magnet within a terrestrial globe, and observing the phenomena exhibited by a small needle, suspended, at its centre of gravity, by a fine thread or fibre. As

the magnet is placed out of the axis of rotation, the needle in the northern hemisphere will always point to the north end of the enclosed magnet, exhibiting all the phenomena of the variation of the needle, as usually observed. The general phenomena of the dip will also be exhibited. * * * * There will be no dip at the equator, because each pole is equally attracted by the corresponding poles of the magnet; and at the north and south poles the dip will be 90°. * * * * At latitudes intermediate between the magnetic equator and the magnetic poles, the dip will have an intermediate value. In the same manner as a common bar magnet communicates magnetism to a piece of soft iron held near it, the supposed magnet in the earth communicates magnetism to a soft iron bar held in the magnetic meridian, and parallel to the dipping-needle, which, in this country, is not far from a vertical position. The soft iron is temporarily a magnet, exactly like the soft bar in the presence of a real magnet, and possesses the very same properties."

Many phenomena, however, would fail to be satisfactorily accounted for under such a theory, and especially as it could only account for the presence of two in place of four magnetic poles.

Another theory is that which supposes the magnetism of the earth to proceed from a magnetised spherical shell, as one of iron; and not in the form of the bar, as proposed by Gilbert. On this Sir D. Brewster remarks—"The difference between these two magnetic states is very great. In regular magnets the centres of action are placed at their extremities, or poles; but in masses of iron, either hollow or filled, either regular or irregular, the centres of action are always coincident with the centre of attraction of the surface and of the mass. When the observations on the variation and dip of the needle became numerous and accurate, philosophers soon perceived that they could not be explained by the action of two magnetic poles at a distance from each other.

"M. Biot had the merit of first viewing the subject in this light; and he, at length, came to the conclusion, that the nearer the poles were taken to each other, the greater was the agreement between the computed and observed results; and by assuming the two centres as indefinitely near to each other in the centre of the earth, the coincidence between observation and calculation was as great as could be expected. Now it is a remarkable fact, that Mr. Barlow discovered that such a coincidence in the centre of action actually takes place in all bodies which are magnetic by induction, such as iron spheres or shells; and he applied this principle to account for the various phenomena of the dip and variation of the needle. Almost all the philosophers who have since investigated the subject have adopted this idea; and the only difficulty which attaches to it is, where to find the cause by which the earth's magnetism is induced. The following speculations on this curious subject are hazarded by M. Hansteen, in his work on the magnetism of the earth:—

"'For these reasons, it appears most natural to seek their origin in the sun, the source of all living activity; and our conjecture gains probability from the preceding remarks on the daily oscillations of the needle. Upon this principle the sun may be conceived as possessing one or more magnetic axes, which, by distributing the force, occasion a magnetic difference in the earth, in the moon, and all those planets whose internal structure admits of such a difference. Yet, allowing all this, the main difficulty seems not to be overcome, but merely removed from the eyes to a greater distance; for the question may still be asked, with equal justice, *Whence did the sun acquire its magnetic force?* And if from the sun we have recourse to a central sun, and from that again to a general magnetic direction throughout the universe, having the milky way for its equator, we but strengthen an unrestricted chain, every link of which hangs on the preceding link, no one of them on a point of support. All things considered, the following mode of representing the subject appears to me most plausible:—If a single globe were left to move alone freely in the immensity of space, the opposite forces existing in its material structure would soon arrive at an equilibrium conformable to their nature, if they were not so at first, and all activity would soon come to an end. But if we imagine another globe to be introduced, a mutual relation will arise between the two; and one of its results will be a reciprocal tendency to unite, which is designated, and sometimes thought to be explained, by the merely descriptive word attraction. Now, would this tendency be the only consequence of that relation? Is it not more likely that the fundamental forces, being driven from their state of indifference or rest, would exhibit their energy in all possible directions, giving rise to all kinds of contrary action? The electric force is excited, not by friction alone, but also by contact, and probably also, though in smaller degrees, by the mutual action of two bodies at a distance; for contact is nothing but the smallest possible distance, and that, moreover, only for a few small particles. Is it not conceivable that magnetic force may likewise originate in a similar manner? When the natural philosopher and the mathematician pay regard to no other effect of the reciprocal relation between two bodies at a distance, except the tendency to unite, they proceed logically if their investigations require nothing more than a moving power; but should it be maintained that no other energy *can* be developed between two such bodies, the assertion will need proof, and the proof will be hard to find.

"'I reckon it possible, therefore, that, by means of the mutual relations subsisting between the sun and all the planets, as well as between the latter and their satellites, a magnetic action may be excited in every one of those globes whose material structure admits of it, in a direction depending on the position of the rotatory axes with regard to the plane of the orbit. Each of the planets might thus give rise to a particular magnetic axis in the sun; but as their orbits make only small angles with the

sun's equator and each other, their magnetic axes would perhaps, on the whole, correspond with the several rotatory axes. Such planets as have no moons, would, on this principle, have but one magnetic axis ; the rest would, in all cases, have one axis more than they have moons, if those different axes, by reason of the small angles which the orbits of their several moons form with each other, did not combine into a single axis. The conical motions by which the rotatory axes of the planets are carried round the pole of the ecliptic (the precession of the earth), joined to the revolving motion of the orbits about the sun's equator (which occasions the present diminution in the obliquity of the ecliptic), might perhaps, in this case, account for the change of position in the magnetic axis. It would greatly strengthen this hypothesis, if the above great magnetic period, after the lapse of which both axes again assume the same position, should, in fact, coincide with the period of precession; which, however, seems a little doubtful.' "

Ingenious and elaborate as is this theory, it has the fatal quality of assuming too much that requires to be proved to make the theory of any value. In its construction it somewhat reminds us of the epicycle theory of the ancients. The fact is, it was founded on narrow and uncertain data ; and the only thing of value that remains in it, is the connection assumed between the sun and the magnetism of the earth, which daily gains deeper credence with philosophers.

Sir David Brewster made the remarkable discovery, that there are, in the northern hemisphere, two poles of extreme cold—not, of course, at the north pole of the earth, but coincident with its magnetic poles ; that the circle of maximum heat, like the magnetic equator, did not coincide with the equinoctial line ; that the isothermal (equal heat) lines, and the lines of equal magnetic intensity (isodynamic lines, explained at p. 352, *ante*), had the same general form, surrounding and enclosing the magnetic poles, and those of maximum cold ; and that by the same formula, *mutatis mutandis*, we could calculate the temperature and the magnetic intensity of any point of the globe.

Now this was a great advance in attempting to account for the cause of terrestrial magnetism. It preceded the discovery of the facts in connection with electricity, electro-magnetism, earth and air currents, &c., &c., which combinedly enable us to frame much better approximations to truth in theory than had been possible thirty or forty years ago.

At that time (1830, or thereabouts), Faraday commenced the interesting investigations in voltaic electricity, electro-magnetism, &c., that have rendered his name so famous, and will ever keep up the reputation of that great philosopher, although he has passed away from the scene of his labours. Writing in the year above named, Brewster remarks—"The monthly and daily changes in the intensity of terrestrial magnetism, and in the dip and variation of the needle, had led Canton and others to ascribe these changes to the action of the sun ; and Captain Duperrey, in his paper on the magnetic equator, ascertained that the points of this great circle, or those where the magnetic intensity is at a minimum, are also the warmest points of each meridian ; or that the thermal and the magnetic equator are connected, as had already been proved to be the case with the thermal and magnetic poles. He likewise attributed the differences in the magnetic intensity of different places to their difference of temperature ; and he remarks, that in comparing the isothermal and the isodynamic lines, he found a remarkable analogy in their curvatures, and particularly in the direction of their concavities and convexities. In support of these views, Duperrey refers to the changes in the daily variations, as following the movements of the sun ; and he infers that the southern hemisphere of our globe is a degree colder than the northern hemisphere."

In 1831, in the *Philosophical Transactions* of the Royal Society, appeared a paper *On the Probable Electric Origin of all the Phenomena of Terrestrial Magnetism*, by the late Mr. Barlow. Sir David Brewster lays claim to having first propounded "the electro-magnetic hypothesis:" but, in his *Treatise on Magnetism*, frankly remarks that his views were "ably supported by the paper just referred to." Sir David, quoting from that paper, remarks, "that the late Mr. Barlow considers it as probable, 'that magnetism, as a distinct quality, has no existence in nature.' As all the phenomena of terrestrial magnetism can be explained on the supposition that the magnetic power resides on its surface, it occurred to Mr. Barlow, that if he could distribute over the surface of an artificial globe a series of galvanic currents, in such a way that their tangential power should everywhere give a corresponding direction to the needle, this globe would exhibit, while under electrical induction, all the magnetic phenomena of the earth upon a needle freely suspended above it. He accordingly put this idea to the test of experiment in the following manner :—

" 'I procured,' says he, 'a wooden globe sixteen inches in diameter, which was made hollow for the purpose of reducing its weight ; and, while still in the lathe, grooves were cut to represent an equator, and parallels of latitude at every $4\frac{1}{2}°$ each way from the equator to the poles : these grooves were about an eighth of an inch deep and broad ; and lastly, a groove of the same breadth, but of double the depth, was cut like a meridian, from pole to pole, half round. These grooves were for the purpose of laying in the wire, which was effected thus : The middle of a copper wire, nearly ninety feet long, and one-tenth of an inch in diameter, was applied to the equatorial groove, so as to meet in the transverse meridian ; it was then made to pass round this parallel; returned again along the meridian to the next parallel ; then passed round this again ; and so on, till the wire was thus led in continuation from pole to pole.

" 'The length of wire still remaining at each pole was bound with varnished silk, to prevent contact, and then returned from each pole

along the meridian groove to the equator. At this point, each wire being fastened down with small staples, the wires for the remaining five feet were bound together to near their common extremity, where they opened to form two points for connecting the poles of a powerful galvanic battery.

" 'When this connection was made, the wire became, of course, an electric conductor, and the whole surface of the globe was put into a state of transient magnetic induction; and, consequently, agreeable to the laws of action before described, a neutralised needle, freely suspended above such a globe, would arrange in a plane passing from pole te pole through the centre, and take different angles of inclination, according to its situation between the equator and either pole.

" 'In order to render the experiment more strongly representative of the actual state of the earth, the globe, in the state above described, was covered by the gores of a common globe, which were laid on so as to bring the poles of this wire arrangement into the situation of the earth's magnetic poles, according to the best observations we have for this determination. I therefore placed them in latitude 70° north and 72° south, and on the meridian corresponding with longitude 76° west, by which means the magnetic and true equators cut one another in about 14° east, and 166° west longitude.

" 'The globe being thus completed, a delicate needle must be suspended above it, neutralised from the effect of the earth's magnetism, according to the principle I employed in my observations on the daily variation, and described in the *Philosophical Transactions* for 1823; by which means it will become entirely under the superficial galvanic arrangement just described. Conceive now the globe to be placed so as to bring London into the zenith; then the two ends of the conducting wire being connected with the poles of a powerful battery, it will be seen immediately that the needle, which was before indifferent to any direction, will have its north end depressed about 70°, as nearly as the eye can judge, which is [was at the date this was written] the actual dip in London. It will also be directed towards the magnetic poles of the globe, thereby also showing a variation of about 24° to 25° to west [that is, in 1829], as is also the case in London If, now, we turn the globe about on its support, so as to bring to the zenith places equally distant with England from the magnetic pole, we shall find the dip remains the same; but the variation will continually change, being first zero, and then gradually increasing eastward, as happens on the earth. If, again, we turn the globe so as to make the pole approach the zenith, the dip will increase, till at the pole itself the needle will become perfectly vertical. Making now this pole recede, the dip will decrease till at the equator it vanishes, the needle becoming horizontal. Continuing the motion, and approaching the south pole, the south end of the needle will be found to dip, increasing continually from the equator to the pole, where it again becomes vertical, but reversed as regards its verticality at the north pole.' "

Mr. Barlow and Sir David Brewster must be allowed the greatest credit for the sagacity which they evinced in including all the known phenomena of electricity, magnetism, and electro-magnetism, as explanatory of terrestrial magnetism, at the time the preceding theory was enunciated; but, as the late Mr. Barlow justly observed, " we have no idea how such a system of currents can have existence on the earth; because, to produce them, we have been obliged to employ a particular arrangement of metals, acids, and conductors."

So far our early theories of magnetism were defective, simply because, as already remarked, many of the phenomena of electricity and magnetism were undiscovered. But Brewster adds —"The discovery of Dr. Seebeck—that the mere application of heat to a circuit composed of two metals, is capable of developing the magnetic effects precedingly described—is regarded, by Mr. Barlow, as bringing us a step nearer to an explanation of the earth's magnetism, by referring us to the sun as the great agent of all these phenomena; and he conceives that only one link is wanting to complete the explanation. The link, however, is a very important one; and we are just as much puzzled to discover the metallic thermo-magnetic apparatus, as we are to discover the electro-magnetic one [difficulties since solved, to a certain extent]. If it could be shown that the action of solar heat is capable of developing magnetism in particles, such as those which are known to constitute our globe, the great difficulty would be [and almost has been] removed." The remainder of the theory we decline to quote, as it is too romantic to deserve even attention. It refers to supposed "ferruginous [or iron] materials, which are disseminated through the mass of the earth, or throughout its atmosphere." This theory has not the least basis of fact, and greatly discredits its originators; for we well know that no form of iron exists in our atmosphere detectable by any chemical analysis, and not even by the very recent method of spectrum analysis, which would show the presence of one grain of iron in not less than 100,000,000 grains of atmospheric air. Independent of the presence of iron, if possible, in the air, we shall subsequently notice that all bodies are capable of magnetic conditions.

To form a reliable theory in respect to the magnetism of the earth, must, from our present knowledge of magnetic, electric, and other analogous phenomena, be beyond the power of man's intelligence. If any remarks that we may make are considered as opposed to the theories of the times, we trust they will only be accepted as an acknowledgment of ignorance of modern philosophers. Nothing is easier than to form a theory; and nothing more difficult than to prove the basis on which that is presumed to be founded; and magnetic theories, as we have previously remarked, are, of all others, the most difficult to deal with.

In the first place, it would seem, from modern

observations, that the sun, its heat, or some power resident therein, directly affects the periodic magnetism of our earth. This is not a matter of opinion, but one of constant daily—nay, hourly observation. We know that, at varying periods of the sun's elevation in the heavens—that is, between or before sunrise and sunset—we experience simultaneously a variation in magnetic intensity, sensible heat, and barometric elevation. Again, it is certain that these variations of each phenomena are not accidental. They occur as regularly as the day appears ; and whatever is thus recurrent, shows that a definite cause must be operating. Again, we know that heat can produce electric currents; and, still further, that electric currents are equally productive of magnetic action, properties, qualities, or effects. We may trace, as Ampère has shown, a connection between diurnal magnetic variation, and diurnal changes of heat by solar influence. The principal part of our theories is still further enhanced by the fact that we may detect, in the "photosphere" of the sun, iron in incandescence by aid of spectrum analysis. Indeed, we might go on multiplying facts, in their relation, which seem to prove that the sun is the source of terrestrial magnetism. But, after all, what we know is indicative, rather than provative. If the sun cause the daily variation of the needle, how is it that, in its absence in the arctic regions during winter, the aurora borealis seems to act so strongly on the needle ? Are these magnetic tides, which, like those of the water, act by reaction, producing on opposite sides of the globe two tides ? Again, what means of communication are there between solar magnetism and terrestrial magnetism, if, as we teach, no matter between the sun and earth intervenes, saving a suppository ether ? But to this it may be objected, that gravitation acts on bodies at immense distances from each other. The sun, for example, is distant, so far as we can at present tell, not less than 91,000,000 of miles from the earth ; on the other hand, chemical and cohesive attraction act at distances insensible to human observation. But neither of these attractions have, so far as we yet know, an inductive influence in the manner already adverted to at p. 335, *ante*.

What can we, then, say as to the cause of terrestrial magnetism ? In our opinion, *nothing* that is to be relied on. The position of all philosophers of the present day should only be that of expectancy, rather than certainty. Our stock of facts is enormous ; but their character is that of heterogeneity. In some cases their character is that of identity in respect to pointing to the solution of our difficulties ; in others, they oppose that solution. At times we seem approximating to the discovery of the cause of all force—that is, the cause of matter in motion ; but, for the present, we have rather to guess than pronounce authoritatively ; or if we do the latter, we risk our reputation, and, like the older speculators in science, run the chance of becoming the laughing-stock of those who succeed us, and who shall have discovered more indisputable facts on which to form their theories.

Magnetism of other Bodies than those of or containing Iron.

The fact that iron, of all other bodies, is the most capable of being influenced by magnetic induction, led to the belief that this metal alone could be made magnetic. Subsequent researches showed the error of such a conclusion ; and Faraday subsequently proved that there is no body in nature that can be properly considered as unaffected by magnetism.

When it was discovered that bodies other than iron, *apparently*, were acted on by the magnet, it was supposed that the presence of a minute quantity of iron in their composition was the cause of the magnetic phenomena. But careful experiments showed that, if the most exact chemical analysis were employed, and the presence of iron was undiscovered, still certain bodies indicated not merely the phenomena of general magnetic action, but might also be made polar, and otherwise evince the same phenomena as iron and steel produce.

Brewster, in his *Treatise on Magnetism*, remarks that the most magnetic metal, next to iron, is *nickel ;* and this need not be a matter of surprise when we consider the fact, that nickel has, in its physical, chemical, and other relations, the utmost possible analogy, not to say identity, with iron. It is as infusible as iron ; its salts greatly resemble those of iron ; in appearance it also resembles that metal, and has about the same specific gravity. "It receives and retains communicated magnetism longer than any other metal [save iron] ; and needles of nickel have a distinct polarity. These properties have been found in nickel after it has been repeatedly purified ; though some authors have stated that they could not detect this property in certain specimens. A very decisive and instructive experiment on the magnetic qualities of nickel, was made by M. Biot [see *Traité de Physique*, vol. iii., p. 126]. He possessed a needle of nickel which had been purified by M. Thenard [the celebrated French chemist]. It was 212 millimetres long, six millimetres broad, and its weight was 5·178 grains. Having made a needle of steel of exactly the same dimensions, which weighed 4·586 grains, he magnetised them both to saturation, and caused them to oscillate in the magnetic meridian. The nickel needle performed ten oscillations in 87 seconds, and the steel one effected the same number in 45½ seconds. As the shape of the needle was the same, the *momenta* of their directive forces were directly as their weight, and inversely as the squares of 87 and 45½ seconds ; that is, as 0·3088 to 1 [inversed in order]; or the directive force of the needle of nickel was nearly one-third of that of the steel needle. Now, it is impossible to suppose that purified nickel could contain such a large proportion of iron as is necessary to produce such a degree of magnetic polarity, without its being recognised by the chemist ; and M. Biot supposed that the magnetic power of the nickel might have been still further increased by the

means which are used to modify the coercive power of steel and iron.

"A series of careful experiments were made by Cavallo, on the magnetism of *brass* when hammered. He found that alloy, whether old or new, British or foreign, was made magnetic when placed between two pieces of card, and hammered on an anvil; and that magnetism thus imparted can always be removed by making the brass red-hot, and could [subsequently] be communicated to it. Lest it might be supposed that ferruginous matter might pass to the brass by rents or openings in the card, he hardened a piece of brass by beating it between two large flints, using one piece as a hammer, and the other as an anvil. The hammered brass became magnetic, but not so strongly as before; which arose, probably, from the rough and irregular surface of the flints, which prevented the brass being hardened as uniformly as it was by the steel hammer. The flints, before and after the experiment, did not possess the slightest magnetism.

"The degree of magnetism communicated to brass by hammering, is vaguely stated by Cavallo to have been such 'as to attract either pole of the needle from about a quarter of an inch distance.' The following are the conclusions which M. Cavallo has drawn from these and other experiments:—

"'1st. That most brass becomes magnetic by hammering, and loses its magnetism by annealing or softening in the fire; or, at least, its magnetism is so far weakened by it as afterwards to be only discoverable when set to float on quicksilver.

"'2nd. The acquired magnetism is not owing to particles of iron or steel imparted to the brass by the tools employed, or naturally mixed with the brass.

"'3rd. Those pieces of brass which have that property, retain it without any diminution after a great number of repeated trials—viz., after having been repeatedly hardened and softened.

"'4th. A large piece of brass has generally a magnetic power somewhat stronger than a smaller piece; and the flat surface of the piece draws the needle more forcibly than the edge or corner of it.

"'5th. If only one end of a large piece of brass be hammered, then that end alone will disturb the magnetic needle, and not the rest.

"'6th. The magnetic power which brass acquires by hammering has a certain limit, beyond which it cannot be increased by further hammering. This limit is various in pieces of brass of different thicknesses, and likewise of different qualities.

"'7th. Though there are some pieces of brass which have not the power of being rendered magnetic by hammering, yet all the pieces of magnetic brass that I have tried lose their magnetism, so as no longer to affect the needle, by being made red-hot—excepting, indeed, when some pieces of iron are concealed in them, which sometimes occurs; but, in this case, the piece of brass, after having been made red-hot and cooled, will attract the needle more forcibly with one part of its surface than with the rest of it; and hence, by turning the piece of brass about, and presenting every part of it successively to the suspended magnetic needle, one may easily discover in what part of it the iron is lodged.

"'8th. In the course of my experiments on the magnetism of brass, I have twice observed the following remarkable circumstance:—A piece of brass which had the property of becoming magnetic by hammering, and of losing the magnetism by softening, having been left in the fire till it was partially melted, I found, upon trial, that it had lost the property of becoming magnetic by hammering; but having been afterwards fairly fused in a crucible, it thereby acquired the property it had originally—viz., that of becoming magnetic by hammering.

"'9th. I have likewise often observed, that a long continuance of a fire so strong as to be little short of melting hot, generally diminishes, and sometimes quite destroys, the property of becoming magnetic in brass. At the same time, the texture of the metal is considerably altered, becoming what some workmen call *rotten*. From this it appears that the property of becoming magnetic in brass by hammering, is rather owing to some particular configuration of its parts, than to the admixture of any iron; which is confirmed still further by observing that Dutch plate brass (which is made, not by melting the copper, but by keeping it in a strong degree of heat whilst surrounded by *lapis calaminaris*) also possesses that property—at least, all the pieces of it which I have tried have that property. From these observations it follows, that when brass is to be used for the construction of instruments wherein a magnetic needle is concerned—as dipping-needles, variation compasses, &c., &c.—the brass should be either left quite soft, or it should be chosen of such a sort as will not be made magnetic by hammering; which sort, however, does not occur frequently.'"

Sir David Brewster wisely draws attention to the danger which may exist in using hammered brass bowls as receptacles for the needle of the mariner's compass. Such may most likely be magnetic in their properties.

In relation to the above experiments by Cavallo, we may notice the singular fact, that constant revolution, or the repeated passage of a voltaic current through metals, has a tendency to make them rotten; that is, their fibrous character is lost, and their texture becomes crystalline. Railway axles, and the conducting wires of a voltaic battery, illustrate this.

It will be unnecessary that we should here enter into a disquisition on the magnetic properties generally possessed by all bodies; for this will be more conveniently considered under the head of *Dia-magnetism*. We shall then find, as already stated, that *all* bodies, no matter what may be their physical condition, are, more or less, susceptible of magnetic influence.

Coulomb and others proved that a kind of universal tendency to produce magnetic phenomena existed in matter generally. Sir David Brewster, after recounting the experiments that Coulomb made in that respect, observes—

"Since the time of Coulomb, methods different from his have been employed in developing magnetism in all bodies whatever. [It must be here understood that we are dealing with the subject, at present, historically, and not expositorally.] In order to detect small quantities of iron in minerals [which was then supposed to be the cause of magnetic phenomena in bodies other than recognised as of iron origin or nature], Haüy employed the process of what he called double magnetism. For this purpose he placed a small bar magnet in the direction of the needle, and in the same horizontal plane; the two similar poles being placed towards each other. The magnet being now brought slowly towards the needle, the latter will deviate from the direction of the magnetic meridian, and take a position perpendicular to it—an effect arising from the combined action of the poles of the magnet and of the earth on the magnetism of the needle. In this position, a very feeble *magnetic action* is sufficient to make the needle turn round, and place its south pole opposite the north pole of the needle.

"When the magnet is above the plane of the needle, and their opposite poles placed near each other, the needle does not change its direction while the point of suspension is beyond the bar, and at a suitable distance; but it is not so when the distance changes, for it tends continually to place itself perpendicular to the line of the poles.

"This important subject was afterwards investigated by M. Becquerel, who obtained the following results. His bar magnet consisted of six united bars, each eight decimetres long, and two centimetres broad. The needle was placed at different heights within and without the bar; and he sought to determine, for each height, the horizontal distance from the point of suspension (which is always in the line of the poles) to the nearest extremity of the needle, in order that its direction might be perpendicular to that line. The results were as follow :—

Vertical Distances from the Centre of Suspension to the Bar.	Horizontal Distances of the Centre of Suspension to the Extremity, in order that the Needle might take a perpendicular position.
Millimetres.	Millimetres.
100	60 within.
150	55 ,,
200	46 ,,
250	23 ,,
300	12 ,,
350	45 without.
400	82 ,,

"Hence it appears, that when the centre of suspension is above the bar, the perpendicular position is obtained by increasing the vertical, and diminishing the horizontal, distance; and that both these distances are increased while the centre of suspension is below the bar; and the direction of the deviation depends on accidental causes, and is often determined by the simple motion of the apparatus.

"When M. Becquerel substituted for his magnetic needle a needle of soft iron, the results were exactly the same, differing only in their intensity. We come now to the original part of M. Becquerel's inquiry. Instead of a needle, he used a small paper case filled with *deutoxide of iron*, or a mixture of deutoxide and tritoxide. With the former the effects were the same as with the steel needle; but it was different with the latter, in which one part of deutoxide was mixed with thirty parts of tritoxide.

"If the centre of suspension be placed as near as possible to the north pole of the bar magnet, and in the line of the poles, the paper case will take immediately a direction perpendicular to this line, instead of one coincident with it, as a soft iron needle would have done. If we put it out of this direction, it will return to it by a series of oscillations, whose velocity depends on the quantity of the deutoxide. From this it follows, that *all the south polar magnetism of the paper case is situated on the side of it next the bar magnet, while the north polar magnetism is on the other side*, as may be exhibited by carrying a small magnetic needle along the paper case. Such a distribution of magnetism is impossible in soft iron or tempered steel.

"If the centre of suspension be above the bar, the paper case will deviate from the position which it had at first, and tend to place itself in the direction of the line of the poles—an effect quite opposite to that produced by a steel or iron needle. The following were the experimental results :—

Vertical Distances of the Centre of Suspension from the Bar.	Horizontal Distances of the same Centre to one of the Extremities of the Bar.	Deviation of the Paper Case from the Direction perpendicular to the Line of the Poles.
10 millimetres	5	24°
	10	44
	15	60
	20	73
	25	78
	30	84
20 millimetres	5	50
	10	65
	15	73
	20	77
	30	32
30 millimetres	5	70
	20	76
	30	82

"The *transverse magnetism* acquired by the paper case is permanent for some time, however small may be the proportion of deutoxide which it contains.

"M. Becquerel next filled the paper case with very pure tritoxide, obtained by calcining nitrate of iron. The effect was much weaker than before. When the point of suspension was very near one of the extremities of the bar, the paper case still placed itself in a position perpendicular to the line of the poles; but if this point was placed above or below the bar, changing at the same time the vertical distance, the paper case deviated from its primitive direction, without, however, taking a direction perpendicular to that which it commonly takes when the centre of suspension is very near the extremity. It might be possible, M. Becquerel thinks, to attain the perpendicular direction by

employing much stronger magnets. The following were the experimental results :—

Vertical Distances from the Point of Suspension to the Bar.	Horizontal Distances of the same Point from the end of the Bar.	Deviation from the Direction perpendicular to the Line of the Poles.
Without the Bar.		
5 millimetres	5	25°
	10	34
	15	48
	20	55
	25	70
10 millimetres	5	32
	10	37
	15	43
	20	46
	25	40
Within the Bar.		
5 millimetres	10	26
	15	—
	20	45
	25	51
10 millimetres	10	20
	15	30
	20	45
	25	50

"Whenever the tritoxide contains the smallest quantity of deutoxide, the velocity of the oscillations increases very powerfully. If, for example, we take *two* paper cases, one filled with tritoxide, and the other with tritoxide mixed with one-thirtieth of the deutoxide, the first will perform twelve oscillations in thirty seconds round a direction perpendicular to the line cf the poles, while the other will execute twenty-five in the same time. Hence we may, by this means, readily determine the quantity of the deutoxide of iron contained in the tritoxide.

"M. Becquerel next employed needles of wood, gum-lac, and other substances, which have still a feebler magnetism than the tritoxide of iron. He placed a needle of white wood, *n s*, four centimetres long and two millimetres in diameter, above the interval between the opposite poles of two bar magnets, the distance between the north and south poles being three or four millimetres. The point of suspension was as near as possible to N S. The needle placed itself perpendicular to the line of the poles, N S, in place of the position observed by Coulomb, coincident with N S. It comports itself, therefore, like the mixture of deutoxide and tritoxide of iron, or like the tritoxide alone. But if we separate gradually the extremities, N S, of the bars, the wooden needle will place itself in the line N S, joining the poles, and in the axis of direction. The deviations were as follow :—

Distances of N, S.	Deviation of the Wooden Needles from the perpendicular position.
3 or 4 millimetres	0°
10 "	18
20 "	36
30 "	56

"When the bars are very close, and the needle in the perpendicular position, if we draw it out of this position, and keep it some instants in the direction of this line, it will remain there ; but the smallest motion will cause it to return into its primitive direction, which it takes in preference to any other.

"If we use only one bar magnet, and place the wooden needle precisely opposite one of its poles, and as near as possible to the end of the bar, it will still direct itself perpendicularly to it ; but if, while the point of suspension remains always in this line, we advance it within the bar, the needle will deviate from its direction, without, however, reaching the position of 90°, as will be seen from the following results :—

Distances of the Centre of Suspension from the Extremities of the Bar.	Deviations of the Wooden Needles in Degrees.
5 millimetres	12°
10 "	18

"Beyond ten millimetres the deviations increase insensibly and irregularly, so that they cannot be measured.

"From these interesting experiments, Becquerel concluded, that the magnetic effects produced by a strong bar magnet upon a magnetic needle, or one of soft iron, differ essentially from those that take place in all bodies when the magnetism is very weak. In the former, whatever be their positions or directions, the magnetism is always distributed in the direction of their lengths, to the exclusion of every other direction; whereas, in the tritoxide of iron, wood, and gum-lac, it is distributed in a direction which depends on the distance of the body from the poles of the magnet, so that the distribution varies with the direction which the magnet causes these needles to take in virtue of the action which it exercises over them."

The preceding quotation forms an introduction to the discovery of Faraday, that all bodies may be divided into two classes—namely, bodies *directly* magnetic, and others exhibiting magnetic affections in positions at right angles to those just mentioned. One set of bodies—such as iron, steel, nickel, and cobalt—arrange themselves in a line parallel to the magnetic meridian, and another class take a position magnetically parallel to the magnetic equator; the last mentioned being what Faraday termed the *diamagnetic* bodies.

One of the most remarkable facts, showing that magnetism is of universal influence, is the instance that all bodies in a condition of rotation affect the magnetic needle ; but this is a subject to which we shall presently draw more particular attention. Suffice it for the present to observe, that the electro-magnet, already described at p. 343, *ante*, as formerly in our possession, illustrated the *converse* of the case in an astonishing manner; that is, magnetism immediately affects the rotation of bodies. A copper disc, twelve or fifteen inches in diameter, was so placed as to form a plane at right angles to the poles of that electro-magnet, and suspended on a pivot to revolve on its axis. Of

course, its rotation or revolution was easily effected by means of a handle between the poles of the unexcited magnet. But the moment the latter was made magnetic, by passing the current of a battery of the power mentioned at the page just referred to, it was barely possible to turn the copper disc round by the force of two hands applied to the handle. This remarkable fact, easily repeated under much less powerful magnetic influences, shows that magnetism has a universal action on bodies, and that, dynamically, it is a great force in nature.

Continuing, and, for the present, concluding, the historical account of this interesting subject, we quote from Sir David Brewster :—

"The universal prevalence of magnetism in all bodies whatever has been established by a beautiful discovery of Arago. This distinguished philosopher conceived the idea of studying the oscillations of a magnetic needle when placed above, or near, any body whatever. Having suspended a magnetic needle above metal, or even water, and caused it to deviate a certain number of degrees from its position [that is, its natural one], it began, when left to itself, to oscillate in arcs of gradually decreasing amplitude, as if it had been placed in a resisting medium; and what was peculiarly curious in these experiments, this diminution in the amplitude [or extent in arc] of the oscillations did not alter the number of oscillations which were performed in a given time. The following were some of Arago's experiments with water, ice, and glass, the semi-amplitude of the oscillations being at the instant 43°.

The distance of the water from the needle was . . } 0·65 millim.
The amplitude lost 10° in . . 30 oscillations.
When the distance was . . 52·2 millim.
A loss of 10° of amplitude required 60 oscillations.

That is, the number of oscillations required to diminish the amplitude 10° was twice as great when the distance of the needle from the water was 52·2 millimetres, as when it was 0·65.

"By placing the same needle upon ice, M. Arago obtained the following results :—

Distances of the Needle from the Ice.	Diminution of the Amplitude.	Number of Oscillations by which this diminution was effected.
0·70	from 53° to 43°	26 oscillations.
1·26	from 53 to 43	34 ,,
30·50	from 53 to 43	56 ,,
52·20	from 53 to 43	60 ,,

"By placing another needle near a plate of crown glass, he obtained the following results :—

0·91	from 90° to 41°	122 oscillations.
0·99	from 90 to 41	180 ,,
3·04	from 90 to 41	208 ,,
4·01	from 90 to 41	221 ,,

"Plates of metal afforded M. Arago similar results; but he, nevertheless, observed that those metals which act with more energy than glass, wood, &c., have a mode of action different from that of these substances. From all these results, it is manifest that all bodies, when placed near a magnetic needle in a state of oscillation, exercise over it an action, the effect of which is to diminish the amplitude of its oscillations, without altering their number; and hence the doctrine of the universal prevalence of magnetism in all bodies derives a new confirmation.

"When Seebeck, of Berlin, heard of the discovery of Arago, he made a magnetic needle, $2\frac{1}{8}$th inches long, oscillate at a distance of three lines* above plates of various bodies, and counted the number of oscillations which were required in each case to reduce the amplitude from 45° to 10°. They were as follow :—

Substances employed.	Thickness of Plate in Lines (1-12th inch).	Number of Oscillations of the Needle.
Marble	1·00	116
Mercury	2·00	112
Bismuth	2·00	106
Platina	0·40	94
Antimony	2·00	90
Lead	0·75	89
Gold	0·20	89
Zinc	0·50	71
Tin	1·00	68
Brass	2·00	62
Silver	0·30	55
Iron	0·40	6

"By alloying magnetic with non-magnetic substances, compounds were formed that had no action on the magnetic needle. The alloys which had particularly this singular property were those consisting of four parts of antimony and one of iron, or two parts of copper and one of nickel. In these cases the magnetism of the two ingredients must have been neutralised by their opposite actions."

The preceding facts and experiments will have shown, to a certain extent, that all bodies are susceptible of magnetic influence; but the subject will be still further generalised when we treat on dia-magnetism as developed by the experiments of Faraday and other philosophers.

From what has been stated, it is evident that magnetism is a force of very general action; and that although we are most familiar with it in connection with iron and steel, still its influence is far greater than would be imagined by the limits of its apparently maximum existence in those bodies. In this, as in every other branch of experimental science, our first discoveries most impress the mind; and it is not until our early views or opinions are chastened by enlarged experience, that we are capable of advancing from particular to general views, and so of obtaining an adequate or accurate knowledge of the subjects we profess to investigate impartially.

We now turn to consider—

The Effect of Rotation on Magnetic and Non-magnetic Bodies, in respect to Magnetism.

It has long been an opinion amongst philosophers, that all the forces in nature have one

* A *line* equals the twelfth part of an inch.

origin, although they are characterised by many forms of development—a subject that we had frequently to deal with in the preceding pages; but one that, as yet, remains unsettled both in theory and in fact. One of the most interesting discoveries, bearing on the point, that have yet been made, is that of the development of magnetism in all bodies by rotation.

Arago was the first to conceive that the magnetic needle would be acted on by rotatory plates of metals, apparently non-magnetic in themselves, but which, by motion, might assume magnetic conditions, or, at least, produce results apparently congruous therewith. By a carefully-devised arrangement, he showed that a rapidly revolving disc of copper affected the magnetic needle, drawing it out of the magnetic meridian, and that the degree of force exerted on the needles was proportionate to the rapidity of rotation of the plate.

The results thus obtained are described as follows by Brewster:—"As the force with which the needle is dragged from its place is opposed to the magnetic action of the earth, which tends to keep the needle in the magnetic meridian, the needle will take a position of equilibrium depending on the ratio of these forces. When the motion of the copper disc, however, is very rapid, the magnetism of the earth is overpowered by that of the revolving plate, and the needle does not stop, but continues to turn. The action of the revolving disc decreases in proportion as the distance of the needle from the revolving plate is increased, the velocity being the same; so that if the motion of the needle be continuous when the two bodies are separated only by a sheet of paper, the needle will take a fixed position by increasing its distance from the plate; and its deviation from the magnetic meridian becomes less and less as it is removed to a greater height above the disc. When the plates have portions cut out in the direction of their radii, their action on the needle is diminished.

"In trying plates of various metals, M. Arago found the results so dependent on the alloy which the metals contained, that he did not publish the results which he obtained. He devoted his attention to the determination of the directions of the force which is developed in the revolving discs; and for this purpose he sought the components of this force in the direction of three lines parallel to three co-ordinate planes perpendicular to each other. The *component* perpendicular to the plate he found to be a repulsive force, which may be rendered sensible by means of a very long magnet suspended by a thread vertically to the extremity of the arms of a balance kept in equilibrium by a weight at the other extremity. The moment that the plate begins to revolve, the magnet is repelled, and the beam of the balance inclines to the other side. The *second* component is horizontal and perpendicular to a vertical plane, which contains the radius abutting against the projection of the pole of the needle. This is the force which gives a motion of rotation to the needle, and it acts in the direction of a tangent to the circle. The *third* component is parallel to the radius which abuts against the projection of the pole of the needle. It may be determined with a dipping-needle, placed vertically so that its axis of rotation is continued in a plane perpendicular to one of the radii of the disc. A similar needle, placed at the centre of the disc, experiences no action. There is, also, a second point, nearer the margin than the centre, where a needle experiences no change in its position: but between these points the lower pole is constantly attracted towards the centre, while it is repelled beyond that point."

Sir David Brewster continues to observe on the history of this singular discovery—"No sooner were M. Arago's experiments announced to the Institute [of France], which was done at the sitting of 7th March, 1825, than philosophers in every part of Europe repeated them, and succeeded in adding several important facts to those discovered by Arago. Babbage, Herschel, Nobili, Baccilli, Christie, Prevost, and Colladon, took a prominent part in these researches. The results obtained by Messrs. Babbage and Herschel were the most important, and the experiments were made in a manner different from those of Arago. A horse-shoe magnet, which lifted twenty pounds, was made to revolve rapidly round its axis of symmetry, placed vertically with its poles uppermost. A circular disc of copper, six inches in diameter, and one twenty-fourth of an inch thick, was suspended above the revolving magnet. As soon as the rotation of the magnet commenced, the copper disc began to turn in the same direction, at first slowly, but afterwards with an increasing velocity. When the magnet was made to turn in the opposite direction, the disc of copper changed the direction of its motion also, and exhibited the same phenomena. Metallic plates, ten inches in diameter and half an inch thick, when interposed between the magnet and the copper disc, did not sensibly modify the results, as M. Arago has observed. Glass produced no effect; but a sheet of tin-plate iron diminished greatly the influence of the magnet, while two such plates almost destroyed it. They also found that a disc of copper, ten inches in diameter, and half an inch thick, and revolving with a velocity of seven revolutions in a second, did not communicate any motion to a similar disc freely suspended above it.

"In comparing the influence of different metals, each disc had the same diameter and the same velocity; and the following were the results which were obtained by this and another method of observation:—

	Ratio of the Force to that of Copper.	Ratio by another Method.
Copper	1·00	1·00
Zinc	0·90	1·11
Tin	0·47	0·51
Lead	0·25	0·25
Antimony	0·11	0·01
Mercury	0·00	0·00
Bismuth	0·01	0·00
Wood	0·00	0·00

"The second method of observation by which

the results in the last column were obtained was more expeditious than the first. Portions of different bodies, of the same form and dimensions, were suspended above a revolving magnet, and the time of successive oscillations and the points of equilibrium were observed.

"Our authors next sought to determine the effect produced by a severance of continuity in the metallic disc upon which the revolving magnet acted. For this purpose, a disc of lead, twelve inches in diameter, and one-tenth of an inch thick, was suspended at a given distance from a horse-shoe magnet revolving with ordinary rapidity, first in its entire state, and afterwards when cut with slits [first, as a radius from the centre; secondly, with a diametrical slit, then with four radial slits at right angles to each other, one with six radial slits, and another with eight.]

The accelerated forces, represented by $\frac{s}{t^2}$ where s is the number of the revolutions, and t the time employed, were as follow:—

Uncut. Disc.	Disc with 1 cut.	Disc 2 cuts.	Disc 4 cuts.	Disc 6 cuts.	Disc 8 cuts.
1258	1047	913	564	432	324

"Effects similar, but differing in degree, were obtained with other metals. With soft tinned iron the cutting produced a very slight diminution of effect, whilst in copper the same operation reduced the accelerating force in the ratio of five to one.

"Messrs. Babbage and Herschel next tried the effect of filling up the cuts with other metals. A light copper disc, suspended at a given distance above a revolving magnet, performed six revolutions in 54″·8. When it was cut in eight cuts, its magnetic action was so weakened that it took 121″·3 to perform six revolutions. When the eight open radial spaces were filled with tin, its magnetic action was restored to such a degree that it made six revolutions in 57″·3. This fact is very interesting, as tin has less than half the [magnetic] energy of copper. The following results were obtained from other experiments, the number representing the accelerating forces or the magnetic energies developed in the plates.

Brass not cut	1·00
Brass cut	0·24
Brass soldered with bismuth	0·53
Brass soldered with tin	0·88
Copper not cut	1·00
Copper cut	0·20
Copper soldered with tin	0·91

"In determining the law of the force, in relation to the distance, Babbage and Herschel found it to vary between the ratio of the square and the cube of the distance [of course inversely]. Mr. Christie found, that when the revolving disc was thick, and the needle delicate, the force which produced the deviation of the needle increased directly as the velocity of rotation, and inversely as the fourth power of the distance. Prevost and Colladon found that the angles of deviation, and not their sines, increased in the direct ratio of the velocity, at least within certain limits; and that the sines of the angles of deviation were in the inverse ratio of the two and a-half power of the distance.

"Haldat made some interesting experiments on this subject. He found that every needle, however weak was its magnetism, obeyed the action of the revolving discs, but that this action disappeared entirely when its polarity disappeared. He found it impossible to magnetise needles by the action of the revolving disc, however rapid; and in consequence of ascribing this effect to the want of coercive power, he employed discs of iron and steel, both soft and hardened.

"A disc of soft iron acted with more energy than one of copper; and, with the same velocity, it dragged the needle twice the distance that a brass disc did. But a disc of untempered steel, one twenty-fifth of an inch thick, did not produce any appreciable effect on the magnetic needle, which, after a few irregular oscillations, maintained its ordinary position of equilibrium. Hence Haldat concluded, that the force which acted upon it was in the inverse ratio of the coercive force. He also found, that discs in a state of incandescence exercised the same action as those of an ordinary temperature."

In the preceding account of the experiments carried out by some of our most eminent philosophers, both past and present, we find a most interesting subject for reflection in regard to the mutuality of the production and exhibition of force in nature. The term force can hardly be understood except in relation to its connection with matter at rest or in motion. The latent forces of nature give us the idea of *statics*, or latent forces, while force in action gives us analogically the idea of *dynamics*, or force in action, motion, or producing some result evident to our senses. This law or circumstance is amply illustrated in the experiments that have been described. So long as plates non-magnetic in themselves were at rest, and composed of metals, we generally deem as non-susceptible of receiving or retaining magnetism, they exhibited no effect in the magnetic needle; but when motion was communicated to them this apparent indifference to the magnetism of a magnetic needle disappeared, and it was found that a rapidly revolving body, of itself non-magnetic, speedily showed magnetic affections.

Some very interesting results were arrived at by the late Mr. Barlow, who experimented on the rapid revolution of a bomb-shell of iron. He found that a variety of opposite effects on the needle were produced according to the direction of rotation of the ball in respect to the needle. He also tried experiments with solid and hollow balls in motion, and arrived at the result, that, when both revolved at the rate of 640 turns per minute, the—

"Mean deviation of the solid ball was 28° 24′, the ball weighing sixty-eight pounds; and the mean deviation of the hollow ball was 15° 5′, with a weight of thirty-four pounds."

From which it would appear that the effect of the respective balls on the needle was directly as their masses.

Mr. Christie communicated to the Royal Society some interesting results that he had obtained *On the Magnetism of Iron, arising from its Rotation;* the method which he adopted being that of causing circular plates of iron to rotate in any desired position in respect to the magnetic meridian. He propounded the following general law of the deviation due to rotation :—

"I refer the deviations of the horizontal needle to the deviations of magnetic particles in the direction of the dip, or to those of a dipping-needle [see *ante*, p. 350] passing through its centre; so that, in whatever direction this imaginary dipping-needle would deviate by the action of the iron, the horizontal needle would deviate in such a manner as to be in the same vertical plane with it. Thus, when the north end of the horizontal needle deviates towards the west, and, consequently, the south end towards the east, I consider that it has obeyed the deviation of the axis of the imaginary dipping-needle, whose northern extremity has deviated towards the west; so that the western side of the [magnetic] equator of this dipping-needle has deviated towards the south pole of the sphere, and its eastern side towards the north pole. It would follow, from this, that if the north and south sides of the equator of the dipping-needle (referring to those points in the horizon) deviated towards the poles, no corresponding deviations would be observed in the horizontal needle; the effect, in this case, taking place in the meridian, would only be observable in the angle which the dipping-needle made with the horizon. * * * It will be found, that the deviations of the horizontal needle due to rotation are always such as would be produced by the sides of the equator of this imaginary dipping-needle deviating in directions contrary to those in which the edges of the [rotating] plate move, that edge of the plate nearest to either edge of the equator producing the greatest effect on it.

"From another set of experiments, Mr. Christie also found, that the effect produced on the iron by its rotation is permanent so long as the plate remains stationary—that is, independent of friction; that it is so far independent of velocity, that the iron can scarcely be moved so slowly that the whole effect shall not be produced; and that the whole effect is produced by making it perform one-fourth of a revolution. After Mr. Christie had discovered these peculiar effects, he exhibited some of the phenomena to Mr. Barlow, who conceived that the effect would be increased by rapid rotation, and who was thus led to make the experiments of which we have already given an account; but the phenomena differ essentially from those observed by Mr. Christie—the former being temporary and dependent on velocity, while the latter are permanent, and independent of the rapidity of rotation.

"In comparing the magnetic forces produced by rapid and slow rotation, Mr. Christie found that the forces exerted on the needle during the rapid rotation of the plate, are always in the same direction as the forces which are derived from the slowest rotation, and which continue to act after the rotation has ceased; but that the former forces are greater than the latter. From a mean of all the observations, the forces seem to be in the ratio of seventeen to thirteen, or very nearly of three to two. Hence Mr. Christie conceives that the polarising of the iron in the same direction will account for the phenomena in both cases; but that the intensity of the polarity during the rapid rotation is greater than of that which appears to be permanent after the rotation, whether slow or rapid, has ceased; and that the phenomena observed during rapid rotation are such as should be expected from what have been described as arising from rotation, without regard to its velocity.

"We have already seen that Messrs. Babbage and Herschel interposed plates of various metals between the revolving magnet and the copper disc, and found no perceptible effect to be produced. Sir W. S. Harris, however, has recently shown, that several substances not supposed to contain iron have the power of intercepting the influence of a revolving magnet. A circular disc, being delicately balanced on a fine central point by means of a rim of lead, was put into a state of rotation on a small agate cup, at the rate of 600 revolutious per minute; and a light ring of tinned iron, also finely balanced on a central pivot, was placed immediately over it, at about four inches distance, by means of a thin plate of glass, on which its pivot rested. When the ring of tinned iron began to move slowly on its pivot, by the influence of the magnet revolving below, a large mass of copper, about three inches thick, and consisting of plates a foot square, was carefully interposed between the magnet and the iron ring. The interposition of the copper soon sensibly diminished the motion of the iron disc, and at length arrested it altogether. On withdrawing the copper, the motion of the disc was restored; and the same effects were repeatedly obtained. In this experiment both the magnet and the disc were enclosed by glass shades, and supported on a firm base.

"The same effects were produced by a mass of silver and zinc; but when their thickness was considerably diminished by removing the central plates, the motion of the disc was not impeded. A very great thickness of lead was necessary to stop the disc, in consequence, as Sir W. S. Harris supposed, of its magnetic energy being so much less than that of copper."

We have entered into this lengthened description of the affections of bodies other than of an iron nature, and of the effects of rotation of bodies on the magnetic needles, for two reasons. The experiments detailed, although performed many years ago, have laid the foundation, not only of dia-magnetism as a comparatively new branch of science, but have also led to very greatly enlarged views of the laws of natural forces in general. In the early days of our

scientific pursuits, the variety of detail, in respect to fact, theory, &c., was so numerous as to be highly complexing, but the tendency of scientific research and discovery, during the last fifty years, has been to simplify that which was complex, and generally to reduce in number the ascertained causes of natural phenomena. Ignorance generally is accompanied by a great variety of explanations or theories to account for natural occurrences; and after all our advances, we must confess that we have yet much to discover before we can satisfactorily account for a variety of effects that, at present, we are compelled to assign to many causes, although we suspect them to arise from one. The researches of Faraday, Grove, and other philosophers, on the conservation and the correlation of forces, lead to this view—that light, heat, electricity, magnetism, gravitation, &c., are all modified forms of force created by the action of motion on matter. Indeed, in all our experiments we require motion for the artificial production of phenomena in our laboratories, representing those that we perceive in nature; and in neither case do these phenomena become apparent unless motion has been the first cause.

Connected with the subjects just previously inquired into, are the experiments, by the late Mr. Barlow, on the action of various forms of iron bodies on the magnetic needle, by which he was led to the method of correcting the local variations of the compass-needle, already described at p. 350, *ante*. As previously mentioned, he commenced his experiments with spherical shells; and by means of a very ingenious apparatus, he arrived at the conclusion that—

"In every ball or shell of plain unmagnetised iron, there exists a plane of no attraction, or a plane in which the iron produces no disturbance of the needle, and which plane inclines from magnetic north to south, forming with the horizon an angle equal to the complement of the dip."

"This line," says Sir David Brewster, "on the surface of the ball, may be called the magnetic equator; and taking the meridian which passes through the east and west points as the first, Mr. Barlow was able to designate every part of his iron sphere by the magnetic longitude and latitude of that point.

"Mr. Barlow therefore proceeded to determine whether the quantity and deviation at any point could be expressed by any function of the latitude and longitude of that point, when the mass of the ball and the distance of the needle from it were constant. From the experiments, which it is unnecessary to detail, he found—

"*That the tangent of the deviation of the needle is proportional to the rectangle of the sine and cosine of the latitude, or to the sine of the double latitude.*

"By observing the deviations throughout a great circle in which the longitude was constant, and also in a circle in which the latitude and longitude were variable, he found the following law:—

"*That the tangent of the deviation of the needle is nearly proportional to the sine of the double latitude multiplied by the cosine of the longitude.*

"By comparing the constant numbers obtained on the preceding principles at different distances *from the centre of the sphere*, Mr. Barlow found—

"*That the tangent of the deviation is inversely proportional to the cube of the distance.*

"The remaining object of Mr. Barlow's inquiry was a very interesting one—namely, to determine the law of the deviation as dependent on the mass of the iron ball by the action of which it was produced. The result was equally new and unexpected. He found—

"*That the tangent of the deviation was directly proportional to the cube of the diameter of the ball or shell; but that it is still wholly independent of the mass, being the same in quantity whatever be the thickness of the metal, provided only that it exceed one-twentieth of an inch.*

"Hence it follows, *that the entire magnetic power of an iron sphere resides on the surface, and is independent of the solidity.*"

Captain Kater, by a series of ingenious experiments, subsequently proved the truth of the preceding results; and it was shown still further by Barlow—"1. That though the development of the magnetism of hollow spheres takes place only at the surface, yet the effect, as shown by the tangent of this deviation, is proportional to the cube of the diameter of the sphere.—2. That the tangent of deviation is inversely as the cube of the distance.—3. That the tangent of the deviation is proportional to the sine of the double latitude and cosine of the longitude, the latter being extended from the east and west points." Mr. Barlow also obtained interesting results from investigating the action of simple iron bars and plates; also of the action of irregular masses of iron on the magnetic needle. He found that the action of plain unmagnetised iron on a compass-needle may be referred to two poles indefinitely near to each other in the common centre of attraction of the surface of the body, in respect to bars of iron; and that a similar law prevailed in respect to irregular masses of iron—such, for example, as are commonly found on ship-board.

The Effects of Light and Heat on Magnetism.

From the intimate connection which a variety of concurrent phenomena has shown to exist between the evidencing facts of all forces in nature, it will be no matter of surprise that light and heat should have a direct action on magnetised bodies. Some of the leading facts in reference to this, may, therefore, be briefly pointed out.

In the early part of this century, it was shown, by Morichini, that, by means of the violet rays of light, a steel needle might be permanently magnetised. "The violet light was obtained in the usual manner, by means of a common prism, and was collected into a focus by a lens of sufficient size. The needle was made of soft wire, and was found, upon trial, to possess neither polarity nor any power of attracting iron-filings. It was fixed horizontally on a support, by means

of wax, and in such a direction as to cut the magnetic meridian at right angles. The focus of violet rays was carried slowly along the needle, proceeding from the centre towards one of the extremities, care being taken never to go back in the same direction, and never to touch the other half of the needle. At the end of half-an-hour after the needle had been exposed to the action of the violet rays, it was carefully examined, and it had acquired neither polarity nor any force of attraction. But after continuing the operation twenty-five minutes longer, when it was taken off and placed on its pivot, it traversed with great alacrity, and settled in the direction of the magnetical meridian, with the end over which the rays had passed to the north. It also attracted and suspended a fringe of iron-filings. The extremity of the needle that was exposed to the action of the violet rays, repelled the north pole of a compass-needle. Mrs. Mary Somerville repeated these experiments in another form, and found that the magnetic influence lay in the violet, indigo, blue, and green rays, with decreasing force from violet to green; but that the yellow, orange, and red rays had no such effect, even after continued exposure to them for a lengthened period.

For many years the fact was assumed, from the precedingly-related experiments, that light had the power of communicating magnetic influence to steel. Even Christie, whose name has been frequently mentioned in the preceding pages as an eminent magnetician, obtained results similar to those of Morichini and Mrs. Somerville. In later years, however, the experiments, conducted with greater philosophical precision, failed to confirm the view that light has magnetic influence. On the other hand, Messrs. Knox state—"Having procured several hundred needles of different lengths and thicknesses, and having ascertained that they were perfectly free from magnetism, we enveloped them in white paper, leaving one of their extreme ends uncovered. Taking advantage of a favourable day for trying experiments upon the chemical [actinic] ray (known by the few seconds required to blacken chloride of silver), we placed the needles at right angles to the magnetic meridian, and exposed them for two hours—from 11 to 1 o'clock—to the different refrangible rays of the sun, under coloured glasses. Those beneath the red, orange, and yellow showed no trace of magnetism; while those beneath the blue, green, and violet, exhibited—the two first feeble, but the last strong—traces of magnetism.

"To determine how far the oxidating power of the violet ray is concerned in the phenomenon, we exposed, to the different coloured light, needles whose extremities had been previously dipped in nitric acid; and found that they became magnetic (the exposed end having been made a north pole) in a much shorter time than the others; and that this effect was produced in a slight degree under the red (when exposed for a sufficient length of time), strongly under white glass, and so strong under violet glass, that the effect took place even when the needles were placed in such a position along the magnetic meridian, as would tend to produce, by the earth's influence, a south pole in the exposed extremity." We shall subsequently point out that magnetism has a direct action on a ray of polarised light.

In respect to heat, no doubt can be entertained that it acts powerfully on the condition of magnetised bodies.

Sir David Brewster, in his exhaustive *Treatise on Magnetism*, divides the subject into three branches; treating first on the effect of heat on the development of free magnetism; next, on the anomalous attraction observed during the bright red and red heats; and last, on the effects of heat on the distribution of magnetism in magnets.

Taking, first, *the effect of heat on the development of magnetism in cast and metallic iron*, he remarks—"In the course of his experiments on the relative magnetic power of different kinds of iron and steel, Mr. Barlow was led to the conclusion, that the harder the metal was, the less it exhibited of a magnetic quality—a result which was highly favourable to the hypothesis that the cohesive power of hardened steel not only prevented the entire development of its magnetism, but also the re-combination of the two kinds of magnetism when they are displaced by the action of a powerful magnet. With the view of establishing this hypothesis, Mr. Barlow found it necessary to ascertain whether these different kinds of iron and steel would exhibit the same magnetic powers when reduced to the same degree of softness; which could only be done by heating them in a furnace, and trying their magnetic qualities in that state."

The general results at which the late Professor Barlow arrived, were, "that cast iron is decidedly inferior in its [magnetic] action when cold; and, when hot, possesses a superior power to malleable iron." He also discovered, that a white heat is totally destructive of magnetic induction in iron; "and, also, * * * that every kind of iron or steel has a greater capacity for developing its magnetism when softened by heat than when cold."

In reference to the anomalous attraction in cast and malleable iron, during a bright red and a red heat, Barlow tried many experiments on various qualities of iron; but, as the circumstances are so exceptional in their nature, we need not enter into their discussion.

The effects of heat on the distribution of magnetism in magnets were first investigated by the celebrated Coulomb; and this is a subject of considerable practical importance, especially in relation to the production of artificial magnets, and their constancy of intensity.

"He took a bar of steel, 162 millimetres long, fourteen wide, and weighing eighty-two grammes. This bar was brought to a cherry-red heat, or 900°, and cooled slowly in the air, so as to have no temper. It was then magnetised to saturation, at the temperature of about 12° Reaumur.* In this state the time of making *ten* oscillations was observed. Its temperature was again suc-

* Equal 59° to 60° Fah.

cessively raised so many degrees, and, after being cooled, the time of performing ten oscillations was again measured. The following were the results :—

Temperature in Degrees of Reaumur.	Time of performing Ten Oscillations.
12°	93·0″
40	97·5
80	104·0
211	147·0
340	215·0
510	290·0
680	very great.

"Hence it is obvious that the magnetic intensity of the bar diminishes rapidly as its temperature is raised.

"From another set of experiments, Coulomb concludes, that the tempering of a bar previous to its being magnetised, has no influence until the heat at which it is tempered becomes about 750°. When the tempering is at 900°, the bar will take double the magnetic force that it did at 12° ; the ratio of the time of ten oscillations being 63″ and 93″, the squares of which, to which the magnetic forces are proportional, are nearly as one to two.

"After the magnet had received the hardest temper at 950°, it was magnetised to saturation. When it was brought back, by annealing, to lower temperatures, and again magnetised, the effects were as follow :—

Temperature.	Time of Ten Oscillations of a Bar Tempered at 95°.
12°	63″
80	66
214, blue colour	80
410, colour of water	170

"Hence we see that the progressive rise of temperature alters the magnetism of the bar much more when it had been first tempered towards 900°, and cooled slowly, than when it had been first put into the annealed state.

"When, in the annealed state, the bar is exposed only to temperatures below 500°, it receives its original force by being again magnetised ; but in the state of temper it is not so. Each rise of temperature diminishes perceptibly the magnetic force which the bar can receive from being again magnetised. This is shown in the following table :—

Annealing Temperature.	Time of performing Ten Oscillations when again Magnetised.
12° Reaumur	63·0″
214 ,,	64·5
410 ,,	70·0
900 cherry-red	93·0

"The bar, therefore, attained its maximum energy when tempered at 900°. It then performed ten oscillations in 63″. Setting out from this term, the directive force diminished in proportion as the annealing temperature increased. At 900°, the bar, magnetised anew to saturation, employed 93″ to make ten oscillations, as in the first experiment, which ought to have been the case, as it was brought back to the same state of perfect annealing from which it was at first taken.

"The bars used by Coulomb were about thirty times long as they were thick, and with such bars similar results were always obtained. But this was not the case with larger bars. Having taken a steel wire, 326 millimetres long and four in diameter, he tempered it at 820°, magnetised it to saturation, and determined its directive force. He repeated the same operation after having annealed it at different temperatures, and the following was the result :—

Annealing Temperature, Reaumur.	Time of Ten Oscillations.
12° temperature of the atmosphere	89″
320	75
450 deep red	68
530 less red	70
900 bright cherry	76

"Here the harder the temperature gives the weakest directive force, as we have already seen in the preceding experiments. The maximum effect takes place when the wire is annealed at about 450° ; and this is the general result for all wires or plates whose length is very great in relation to their width."

On this point, M. Biot remarked, "that when magnets are larger, in proportion to their thickness, than those used in the preceding experiments, a greater number of centres will be produced, were it from no other cause than the reaction of the plate upon itself.

We are indebted to Sir David Brewster for the preceding remarks, as also for some of the following.

"In examining the influence of temperature on magnets, Kupffer began by examining the effect of heat in altering the distribution of magnetism. For this purpose he took a parallelopiped of tempered steel, 503 millimetres long, $15\frac{1}{2}$ wide, and 5 thick, and having magnetised it to saturation, he heated it, allowing it to cool slowly before being submitted to magnetisation. The magnet was placed vertically, and a needle, suspended by a silk fibre, was made to oscillate before any point in the magnet, in order to determine the intensity of magnetism at that point. In this way he obtained the following results :—

Distance *ab′* in Millimetres.	Magnet not heated. Magnetic Force.	Same Magnet heated to 80°, and examined after cooling. Magnetic Force.
156·0	0·5569	0·4376
136·5	0·7374	0·5765
116·5	0·9455	0·7280
96·5	1·1862	0·8897
76·5	1·4311	1·0559
56·5	1·6518	1·1929

"Hence it appears that the bar heated to 80° had not only lost much of its magnetic virtue, but

that this loss was not uniform along the whole length of the bar, being greater towards the extremities, a' b', than towards the middle. This may be easily seen by dividing the forces in columns 2 and 3 by one another, when it will appear that the quotients are greater for points nearest a' and b'.

"M. Kupffer next studied the changes which took place in the forces of a magnetic needle when its temperature is increasing, the heat being kept constant during the time of each experiment. He used a cylindrical needle of fused steel, 0·57 millimetres long, and 2·395 grammes in weight. The temperature increased from $8\frac{1}{2}°$ to 18°, and the deviation of 300 oscillations varied from $777\frac{1}{2}$ to 781, which shows, as Coulomb had previously observed, that the magnetic force diminished as the temperature increased. By another series of experiments, M. Kupffer has shown, that the diurnal variations of the needle did not at all affect these results.

"In order to determine the law of the decrease of the magnetic forces at temperatures above 30°, he made a needle oscillate above a newly magnetised bar 0·5 millimetre long, the opposite poles looking to each other, and he raised the temperature of the bar from 13° to 80°, by means of hot water. At 13°, the needle, when by itself, performed 300 oscillations in 762″. When brought to the temperature [Reaumur] in the following table, and then cooled, the oscillations of the needle were observed as follows:—

Temperature of Magnet.	Deviation of 300 Oscillations.
13°	429
80	476
21	$464\frac{1}{2}$
13	463
11	$462\frac{1}{2}$

"Hence it appears that the magnetic force diminishes with heat, and that a magnet, at a temperature of 13° [Reaumur], when heated to 80°, and then cooled to 13°, does not resume its first magnetic state, which is consequently diminished. The cause of this is [partly], that in cooling the bar loses a part of its temper, and, consequently, a part of its free magnetism."

From the preceding facts and experiments, Kupffer deduced a mathematical formula, which satisfactorily expresses the influence of temperature on magnetised steel. It is compounded of all the facts above related, involving the force of terrestrial magnetism on the oscillating needle; the number of seconds in which a definite number of oscillations are performed; the force excited by the bar at a certain temperature; the number of seconds which the needle requires to perform certain oscillations at a given temperature; the intensity of the magnetic force of the bar at a normal (ordinary atmosphere) temperature; and the intensity of the force at 80° Reaumur, or 212° Fah.

Kupffer proceeded to make some interesting experiments in respect to heating only one pole of a magnet, as affecting the distribution of its magnetism. But as we have already sufficiently extended this subject, we shall do no further than notice such investigations.

Christie's experiments, resulting as they did in a close approximation to the foundation of a general law in regard to the effect of heat on magnetised steel, must be noticed.

"In examining the diurnal deviations of the needle when under the influence of magnets, Mr. Christie conceived that the deviations might be partly the effect of changes in the temperature of the magnets; and he therefore undertook a series of experiments to determine the precise effects of changes of temperature on magnets. By a peculiar apparatus, and a method of observation which our limits will not allow us to introduce, he obtained the following results:—

Mean Temperature of the Magnets, Fah.	Difference of Heats in successive Observations.	Magnetic Intensity.	Variation of Intensity for 1° of Fah.
62°·05	— 3°·00	212·5620	0°·1268
59 ·05	+ 18 ·60	212·9423	0 ·1247
77 ·65	— 3 ·65	210·6228	0 ·1004
74 ·00	— 3 ·35	210·9892	0 ·1279
70 ·65	— 3 ·50	211·4178	0 ·1193
67 ·15	— 3 ·35	211·8353	0 ·1138
63 ·80	— 1 ·75	212·2167	
62 ·05		212·4640	0 ·1413

"By discussing these results, Mr. Christie concludes that 0·1226 is the mean variation of the intensity of the magnets, from a change in their temperature of 1° between the temperatures of 59°·05 and 77°·65. Taking the case where the intensity at 60° was 218, the change for 1° was 0·123; and supposing the intensity to be 1, each degree will produce a diminution of 0·000564.

"From a number of experiments made with a balance of torsion, the needle being suspended by a brass wire $\frac{1}{450}$th of an inch in diameter, Mr. Christie ascertained the following facts:—

"1. Beginning with — 3° of Fahrenheit, up to 127°, the intensity of magnets decreased as their temperature increased.

"2. With a certain increment of temperature, the decrement of intensity is not constant at all temperatures, but increases as the temperature increases.

"3. From a temperature of about 80°, the intensity decreases very rapidly as the temperature increases; so that if, up to this temperature, the differences of the decrements are nearly constant, the differences in the decrements also increase.

"4. Beyond the temperature of 100°, a portion of the power of the magnet is permanently destroyed.

"5. On a change of temperature, the most considerable portion of the effect on the intensity of the magnet is produced instantaneously—showing that the magnetic power resides on or very near the surface.

"6. The effects produced on soft iron by changes of temperature, are directly the reverse of those produced on a magnet; an increase of temperature causing an increase in the magnetic

power of the iron. This was observed between the temperatures 50° and 100° Fah. Mr. Christie regards this fact as a strong argument against the hypothesis, that the action of iron upon the needle arises from the polarity which it receives from the earth."

We thus perceive that, to a certain extent, light and heat evidently have relations with magnetic force. When we describe the varied phenomena of electro-magnetism, we shall find that, when a voltaic current is passed through a long heliacal conductor, it has the simultaneous effect of generating heat, light, and magnetism, together with the production of new and intense electrical currents, which, in their turn, again can reproduce precisely the same phenomena in other arrangements. In other words, the voltaic current can not only reproduce apparently itself, but propagate the same power to bodies adjacent to it, but not having the least metallic or electric connection. Thus the feeble current of a single voltaic cell may, by passing through a coil of wire, induce magnetism in a piece of soft iron rod, in the manner already explained at p. 342, *ante*. Then if a coil some miles long be wound over it, and each row of the latter be carefully insulated, all the phenomena of frictional, voltaic, and other conditions of electrical action may be exhibited. Again, this second coil may produce similar effects on another superimposed on it.

We shall also find, that a fixed battery of bar magnets may, by proper arrangements, be made to produce all the phenomena of electricity, frictional and voltaic, by the simple rotation of a coil of wire at its poles. And by this arrangement all the splendid phenomena of the electric light, the heating effects of the voltaic current, its magnetising effects, &c., &c., may be procured.

In fact, as we proceed, it will be impossible not to notice the most intimate connection of all the forces of nature with each other; and equally we discover a gradually progressive step to the assigning of a unity of cause to a series of analogous or identical effects, apparently arising from a diversity of causes, which, however, future discoveries may reduce to one, exercised under a variety of modifying conditions or circumstances.

The Effect of Distance on the Intensity of Magnetism.

At p. 351, *ante*, we entered into a limited description of the method that is adopted of ascertaining the diminution of gravitative attraction on bodies as the distance is increased between the attracting and attracted body. We then pointed out, that in respect to gravitation, so far as our earth is concerned, the oscillation of a pendulum of a given length, per second, or the length of a pendulum required to give a certain number of oscillations per second, might be employed as a measure of the force of gravity at different parts of the surface of the earth; for it is evident, that the nearer the bob of the pendulum is to the centre of gravity of the earth, the quicker will be its oscillation; or, in other words, a pendulum longer at the pole than at the equator, may be made to oscillate at the same rate per second as the shorter one at the latter-named station.

In dealing with gravitation, we have a universally and equally disposed force, acting in straight lines from *one* common centre, which is the centre of gravity of the earth. But this condition does not subsist in respect to terrestrial magnetism, nor in the case of an artificial magnet. In regard to the magnetism of the earth, we have seen, at p. 345, *ante*, that according to the theories, views, or facts of Hansteen and others, there are four magnetic terrestrial poles; and in respect to the intensity of artificial magnets, it has also been generally pointed out, in the preceding pages, that the uncertain composition of the steel, or ore of the natural magnet, or loadstone, introduce several elements of difficulty, that require great skill in manipulation, and judgment in reasoning, to overcome. It need be, therefore, no matter of surprise, that different results have been arrived at, considering the obstacles that philosophers have had to contend with in arriving at the truth regarding the intensity of magnetism.

On this subject many authorities have written, and numerous formulæ have been advanced, to give a mathematical value of the results obtained. For the present, we shall prefer to take the matter partly in an historical and partly in a philosophical view.

Sir David Brewster remarks—"Like all other laws, an approach to the discovery of it had been made by various philosophers; but the merit of its perfect establishment undoubtedly belongs to Robison and Coulomb, the last of whom placed it beyond reach of doubt. The difficulties which were to be overcome in this inquiry, arose from the invariable co-existence of two opposite polarities in each of the two bodies, whose mutual action was under examination; and this difficulty was increased from these polarities not being concentrated in particular points, but diffused, in an unequal degree, over each half of the magnet and needle.

"In this delicate inquiry Coulomb employed two methods. In the first he suspended a magnetic needle by a silk fibre, and when it was on the magnetic meridian, he presented to it, at different distances, another magnetic needle, and determined, by observation and calculation, the force with which they acted upon each other at these distances. A needle an inch long, weighing seventy grains, and magnetised to saturation, was suspended by a fibre of silk three lines long, and a steel wire magnet, twenty-five inches long, was placed vertically in the magnetic meridian at different distances, so that its south pole was always ten lines below the northern extremity of the suspended needle. The needle was now made to oscillate when the magnet was at different distances from it; and the following were the number of oscillations in 60″, the number being fifteen when the magnet was removed, and the needle influenced only by the magnetism of the earth.

Distance of a Wire Magnet from the middle of the Needle.	Number of Oscillations in 60″.
4 inches	41
8 ,,	24
16 ,,	17

"By means of the formula for the pendulum, in which the forces are in the direct ratio of the square of the number of oscillations performed in the same time, Coulomb has computed their intensity. As all the forces concerned are in the plane of the magnetic meridian, the force which produces the horizontal oscillations depends on the parts of these forces which are decomposed in a horizontal direction. Now Coulomb had demonstrated that the magnetic fluid might be considered as concentrated at a point ten lines from the extremity of the wire magnet; but as the suspended needle was one inch long, its north pole was attracted at the distance of three and a-half inches, and its south pole at the distance of four and a-half inches, so that four inches was the mean distance at which, in the first experiment, the lower pole of the wire magnet exerted its action on the two poles of the needle. In the second experiment the mean distance was eight inches. But as the horizontal force which produces the oscillations is as the square of the number performed in 60″, the magnetic force of the earth will be 15^2, and the combined forces of the earth and the wire magnet will, in the first, second, and third experiments, be 41^2, 24^2, and 17^2, so that the forces which emanate from the wire magnet will be $41^2 - 15^2$, $24^2 - 15^2$, $17^2 - 15^2$, whence we deduce the following results:—

Mean Distance.		Force depending on the Action of the Wire Magnet.
1st experiment	4 inches	$41^2 - 15^2 = 1456$
2nd ,,	8 ,,	$24^2 - 15^2 = 351$
3rd ,,	16 ,,	$17^2 - 15^2 = 64$

The distances in the first and second experiments being as one to two, the variation of the force would have been exactly as the squares of these numbers, had the force in the second experiment been 364 instead of 351; and the same would have been the case had the force in the second and third experiments been 332 and 83, instead of 351 and 64. This difference, therefore, requires to be investigated. Coulomb has accounted for it, and calculated the correction for these numbers in the following manner:—In the experiments the action of the superior pole of the wire magnet was neglected. The distance of its inferior pole from the centre of the needle was sixteen inches, and the distance of the superior pole from the centre of the needle is nearly $\sqrt{(16^2 + 23^2)}$, so that the force of the former is to that of the latter nearly as 100 to 10. Hence, as the oscillations of the needle are produced by the action of these two poles, which exert their force in opposite directions, the square of the number of oscillations which the single action of the inferior pole of the magnet would produce, should be diminished $\frac{19}{100}$ths by the opposite action of the superior pole; so that 64 is only the excess of the real amount of the single action of the lower part of the magnet over $\frac{19}{100}$ths of the number which represents it. The true value will therefore be 79. The true intensities of the forces will, at the distances 4, 8, and 16 inches, be 1456, 351, and 79, or nearly in the inverse ratio of the squares of the distances.

"M. Coulomb has in like manner demonstrated, that the repulsive force of similar poles follows the same law of distance."

Coulomb's second method involved the use of an ingenious contrivance, called the magnetic balance. Its construction involves the same principles as those on which the torsion balance depends, which, in the hands of Coulomb, became so useful an instrument of research. It will not be necessary that we should go through all the experiments which that philosopher tried to ascertain the law of decrement of magnetic force. Their result tended to prove that the attractive and repulsive forces of magnets decrease as the squares of the distances increase.

It would thus seem, after rigid inquiry, that magnetism, as with all forces radiating from a centre, obeys the same law; namely, that the intensity—that is, the attractive or repulsive effect of one magnetised body on another, or of a magnetised body on an unmagnetised—is inversely as the squares of their distance. In other words, we mean, that if, at a certain distance, the force equal 1, at double that distance it will be but one-fourth; at three times that distance, one-ninth; and so on. At a subsequent page we shall point out, however, how rapidly the magnetic force decreases as the object attracted or repelled is removed from the influence of the magnets. The large electro-magnet, described at p. 343, *ante*, supported, when fully excited, weight hanging from its keeper equal to tons. But when the keeper was removed, and a needle was delicately poised in the hands at a distance of a few inches, the attractive force was so slight that the needle was not drawn from the hand as it lay thereon. We shall afterwards point out how this fact, for a long time, prevented the successful adaptation of electro-magnetism to the purposes of a motive power.

Magnetic Theories.

We have already stated, that to account for the cause of magnetism is one of great difficulty; and, under the head of Terrestrial Magnetism, a few of the older theories of Hansteen and others, with the more recent one of Barlow, have been recounted.

The theory now generally accepted is that of Ampère, to which we shall presently briefly allude. But to understand it, the student must carefully investigate the theories and facts which will be presented to his notice, under the heads of *Elementary Principles*, and *Various Electro-magnetic Phenomena*, in the subject of electro-magnetism, which will next engage our attention. We have already very cursorily shown that an electrified wire and a magnetised body have

immediate relation in regard to the mutual exercise of their forces on each other. But in the article on Electro-magnetism these questions will be greatly expanded. We shall find that a copper wire may be so affected by voltaic-electric currents as to show all the phenomena of attraction, repulsion, and polarity; that copper, or other (than iron) metallic wires, discs, cylinders, &c., can be made to rotate round the poles of a magnet; and, *vice versâ*, the poles of a magnet are equally capable of revolution round a conductor conveying an electric current. In these facts we shall find such a generalisation of magnetic and electric phenomena, with respect to all their affections, that any difficulty which may have arisen in arriving at a true theory of magnetism from the study simply of magnetic qualities, as evidenced in steel or iron, is greatly alleviated, although many points of uncertainty have yet to be cleared up.

Æpinus was one of the first to give a general theory of magnetism; by which we mean, not simply terrestrial magnetism, that has already been considered, but of magnetism in general. He supposed only the existence of one fluid, or force; but this theory failed in general application in certain particular cases.

Sir David Brewster observes, of theories antecedent to Faraday's first discovery of *volta-electric induction* (1831—'35), which put all magnetic theories then existing on their trial, and proved their incompleteness—"The hypothesis of two fluids, which was first proposed by Wilcke and Brugmann, was established by Coulomb, and has recently (*cir.* 1829–'30) been perfected by the masterly investigations of M. Poisson, who has not only constructed mathematical formulæ which enable us to calculate all the minutest details of the phenomena, but has enabled us to comprehend, physically, how the phenomena have been produced. The general equations at which he has arrived, *have not yet, in every case, been resolved;* but the particular conditions under which the investigations are possible, have already exhibited the most happy coincidence with experiment."

Here, for a moment, we break off in the relation of magnetic hypothesis, as believed forty years ago, for the purpose of remarking on the danger which exists in founding theories on narrow premises. At the time the preceding and following remarks were penned, our knowledge of electro-magnetic phenomena was extremely limited, and dia-magnetic phenomena were utterly unknown. It will be therefore instructive to the student to peruse carefully the following remarks, and eventually to compare the magnetic theories therein suggested, with the facts hereafter to be described in connection with electro-magnetic induction, magneto-electricity, dia-magnetism, and other matters.

"The hypothesis of two fluids supposes that they reside in each particle of iron; that they are neutral and inert when combined, as in soft iron; and that, when they are decomposed, the particles of the *austral* fluid attract those of the *boreal* fluid, and *vice versâ* while they each repel one another.

"In order to account for the phenomena of the division and fracture of magnets, it is necessary to suppose, that when the united fluids are decomposed, the fluids undergo displacement only to an insensible distance. The minute portions of a magnetic body within which the motions and displacements resulting from decomposition take place, or in which magnetism exists, are called the *magnetic elements* of that body, and the small intermediate spaces where magnetism is not found, the *non-magnetic* elements. It is impossible to determine whether the *magnetic elements* are the intervals which separate the ultimate atoms of material bodies, or if they are the atoms themselves; nor can we ascertain whether they are the intervals between an aggregate number of atoms, or of a secondary molecule, or the aggregate members themselves. The theory regards the sum of the magnetic elements and of the non-magnetic elements as forming the apparent volume of a body. The ratio of these two sums may change with the nature and temperature of the body; and these changes exercise a powerful influence over the distribution and intensity of magnetism.

"The quantity of each fluid in every magnetic element is unlimited in reference to our powers of separating them, as the united fluids can never be completely decomposed. The force which prevents this decomposition, and also the re-combination of the fluids, is called the *coercive force;* and, like that of friction, it cannot be completely overcome. In soft iron, this coercive force is extremely feeble. In the natural loadstone, and in steel, it is very powerful, varying in intensity in different kinds of this metal.

"One of the most important consequences of the theory of Poisson is, that a magnetic needle whose size is so small that it exerts no sensible action on an iron sphere within which it is placed, will intercept the magnetic influence of the earth, and of all magnetic bodies without the sphere; and, in like manner, such a sphere will intercept the action of a magnet within it on all bodies without it. Another interesting consequence of the theory is, that in a hollow iron sphere, magnetised by the influence of the earth, or of any magnetic force, the origin of which is at such a great distance that it may be considered as acting in parallel lines, although the magnetism is not confined to the surface of the sphere, and though its intensity may be determined for any particular point of the solid mass of the shell, yet it is determined only by the radius of the external surface, and the co-ordinates of the point upon which the forces act. When this point is very remote from the centre of the sphere compared with its diameter, each of the three forces is nearly in the direct ratio of the cube of the radius, and in the inverse one of the cube of the distance.

"M. Poisson has likewise applied his powerful mind to the explanation of the singular phenomena of magnetism produced by rotation. To the suppositions which his theory makes in order to explain the phenomena of magnetism induced by influence, he adds another—namely,

that all bodies exert, upon the *boreal* and *austral* fluids, a species of action analogous to the resistance of media, which action has the effect of retarding the motion of two fluids in the interior of the magnetic elements; and he conceives, that it is this species of resistance, and not the coercive force, which has an influence over the magnetic phenomena of revolving bodies. Hence, if we bring a magnet near any body on which the coercive force is insensible, and in which the magnetic elements are in any proportion, the decomposition of the neutral fluid will begin immediately, and will continue till the action of the free fluid is in equilibrio with the external force, which will certainly take place if the force be constant in magnitude and direction. But if it varies continually, or if the loadstone changes its position, the two fluids, in place of arriving at a permanent state, will move in each element with velocities dependent, other things being equal, on the resistance which the substance of the body opposes to them."

In regard to the value of the preceding theory, Brewster remarks, with the candour of a philosopher prepared to give up imagination for fact—"It is needless to enter into any further details respecting this very ingenious theory, as the recent discoveries of Mr. Faraday, respecting electro-magnetic induction, have enabled him to give a most satisfactory explanation of the diversified phenomena of magnetism in motion." This was penned about the end of 1836; and little did Brewster or Faraday imagine to what expansion the discoveries made up to that date by Faraday would be developed in the course of the next thirty years. Such will become the subjects of investigation in the following article; but we may give a short summary of Ampère's theory of magnetism, as briefly noticed by Mr. Noad in 1866, which embraces a kind of *résumé* of all the results that a period of thirty years' research had arrived at. The individual character of the bases on which Ampère founded that theory, will be evident as we further study, hereafter, the conjoined phenomena of electricity and magnetism.

"On the analogy which exists between helices and magnets, Ampère founded his theory of magnetism. According to this, the phenomena of magnetism [generally] depend on voltaic currents circulating round the molecules of magnetic bodies. In their unexcited state, these molecular currents move in all directions, and thus neutralise one another; but when a bar becomes a magnet, the currents move parallel to each other, and in the same direction, and the effect produced is that of a uniform current moving corkscrew-fashion round the bar, which thus becomes in effect a helix, and the attractions and repulsions of the magnet are consequences of the actions of the currents on each other. In applying this theory to the explanation of the phenomena of terrestrial magnetism, it is necessary to suppose the incessant circulation of electrical currents round the globe from east to west, perpendicular to the magnetic meridian." This has already been proved; and their production is ascribed, according to the principles of thermo-electricity, to the heating action of the sun at one place; whilst at another, west of it, the earth is cool. Hence a current of electricity would pass from east to west, just as we notice between two bars of antimony and bismuth, from the heated to the cool part by thermo-electrical agency.

The following extract of a report on magnetic disturbance, in regard to variation, dip, &c., annual and diurnal, was communicated to the British Association at a recent meeting, in a letter from Senhor Capello, of the Observatory, Lisbon, to Professor Stewart, of the Kew Observatory. It may be perused in connection with our remarks on the variation of the needle, at p. 345; with that of the dip, at p. 350; and of the intensity of magnetism, at p. 351, *et seq.*, where each of the subjects treated in the following report have been dealt with at length :—

"The author sent three tables, representing graphically the most important results deduced from the curves of the magnetograph for the year 1864. He had followed the plan of General Sabine in separating the greatest disturbances of the three elements. Thus he had considered as a disturbance of the declination every ordinate which differed from the monthly mean by 2·3′ or upwards, while the separating value of the horizontal force was ·0011 of the whole horizontal force, and that for the vertical force ·00032 of the whole vertical force. The instruments were at work during the whole of the year 1864; and of the 8,760 hourly observations of each instrument, the observers only failed in measuring 97 for the declination, 139 for the horizontal force, and 159 for the vertical force instrument. The number of disturbances have been, for the declination, 1,043; for the horizontal force, 810; for the vertical force, 982. From a diagram exhibited, giving the hourly variations yearly and half-yearly of the three elements, it was seen that the progress of the declination for each period is very regular. The mean daily range of declination during the six months from April to September, when the sun is north of the equator, is 9·20′; while during the six months from October to March, when the sun is south of the equator, this range is less, being barely 6′. For the dip the corresponding curves are much disturbed from 6 P.M. to midnight, especially for the six months when the sun is north of the equator. The total force gives a well-pronounced minimum at 11 A.M. during the six summer months, and 11.30 A.M. during the six winter months. The daily range is greatest for the six summer months, and least for the six winter months. The diagram of disturbances gives for the declination a maximum of the westerly disturbances at about 8 A.M., and a minimum about 10 in the evening: on the other hand, the maximum of eastern deviation took place about 10 in the evening, and the minimum about 6 in the morning. The curves for the horizontal force disturbances are irregular. The maximum of disturbances tending to *increase* the horizontal force takes place about noon, while the minimum is about 1 A.M. But here one is much

struck with the great disproportion between the disturbances tending to *increase*, and those tending to *diminish*, the horizontal force, the latter being both the most numerous, and the greatest in amount. The maximum and minimum of these latter disturbances take place a little later than the maximum and minimum of the disturbances tending to increase the force. With respect to the vertical force, the curve of disturbances tending to increase the element, resembles, to some extent, the curve of easterly disturbances, or disturbances tending to diminish the westerly declination. In this same diagram *blue* and *red* curves were made to represent the whole effects of the perturbations, or the quantities which it is necessary to apply to the line of no disturbance, reckoned a straight line, in order to reconstruct the curves with the perturbations. Thus, the effect of disturbances upon the declination is to cause the needle to deviate towards the west during the hours of the day, but towards the east during the hours of the night. The effect of disturbances upon the vertical force is of a reverse kind, tending to diminish the element during the hours of the day, but to increase it during those of the night. With regard to the horizontal force, it appears that the disturbances tend to diminish this element almost during the whole of the twenty-four hours. A third diagram represented the mean hourly movements of the north pole of the freely-suspended needle, in a plane perpendicular to the direction of such a needle, both for the whole year, and also for the winter and summer seasons."

In the preceding pages of this article on magnetism, only so much has been advanced as will enable the intelligent reader to study the subsequent subjects of electro-magnetism and dia-magnetism. Hence we have not gone further into the theories that have been offered to account for magnetic phenomena, which base their object and nature on the relations that subsist between magnetism and electricity.

As we proceed with the subject of electro-magnetism, it will be perceived that magnetic theory can scarcely have the least foundation on facts, arising from a narrower basis than the dual character of these forces, and their mutual connections or relationship. Indeed, if the succeeding remarks on electro-magnetic phenomena be carefully studied, and, still better, if they be experimentally investigated, a theory of magnetism will be gradually perceived to arise in the mind, that, founded on a multiplicity of facts, will force itself with the conviction of truth.

But when, still further, the phenomena of dia-magnetism, as discovered and developed by Faraday, have been examined, much wider views of the nature of magnetism will be arrived at. We shall find that *all* known bodies, solid, liquid, or gaseous, may be divided into two classes; namely, *magnetic* and *dia-magnetic*. The magnetic embraces such bodies as iron, cobalt, and nickel; whilst, with comparatively few exceptions, all other bodies belong to the dia-magnetic class. The magnetic kind, if freely suspended, are acted on by the poles of another magnet, if swinging between, in an *axial* direction; that is, the north pole of one will attract the south pole of the other, and *vice versâ*. Supposing, for example, that the poles of our earth be taken as magnetic poles, then such bodies as the magnetic would arrange themselves in lines corresponding to those of longitude on a map. On the other hand, the dia-magnetics take an exactly opposite direction. They arrange themselves at right angles to the position of the magnetics, under circumstances just described. In other words, keeping up the illustration just given, the dia-magnetic bodies, placed under the action of the poles of a magnet, would arrange themselves equatorially; that is, in a line at right angles to the poles, and like the equator as drawn on a map. Faraday went still further: he succeeded in magnetising a ray of polarised light, deflecting it from its course to a position at right angles to that it previously occupied. But we are anticipating the details of one of the most interesting discoveries, in respect to the forces of nature, ever made by man. We conclude, therefore, by urging on our readers a study of the phenomena of electro-magnetism and dia-magnetism, now to be described; promising that such, if carefully and experimentally performed, will afford deep intellectual pleasure, even to an unscientific person, and an excellent exercise for the reasoning powers.

CHAPTER XIII.

ELECTRO-MAGNETISM.

THE phenomena of nature embraced in the division of philosophy under the name of Electro-magnetism, has, during the last forty years, engaged the attention of experimentalists perhaps more than any other; and, in its applications, it has been exceeded by none in importance.

To Professor Œrsted, of Copenhagen, belongs the merit of first introducing to the scientific world the fact, that an electrified conducting wire has an influence on a magnetised body; and most simply can we illustrate this fact, by stating that a magnetic needle—as that of the mariner's compass—is immediately deflected from its polar position if a current of electricity be passed over or under it.

Although, however, to Œrsted belongs the merit of *proving* that electrified and magnetised bodies have a mutual influence on each other, the fact had been anticipated by other philosophers. Mr. Noad remarks, in the early edition of his *Lectures on Electricity, &c.*—"The disturbance produced on the magnetic needle by the *aurora borealis* [see *ante*, p. 347], and lightning, had long suggested to philosophers that the agencies of electricity and magnetism must be connected by some close and intimate relation. For nearly half a century the discovery of this relation was a favourite object of speculation; and it is curious to compare the various opinions which were maintained by different experimentalists. Magnetic properties were easily communicated to bars of steel by passing strong electrical shocks through them; but no general law could be traced as governing the polarity thereby imparted. Dr. Abilard imagined he had proved that the electric discharge imparts a northern polarity to that point of a steel bar at which it enters, and a southern polarity to that at which it makes its exit; and this quite independently of the position of the needle with respect to the magnetic poles of the earth. Wilke, on the other hand, was equally satisfied that an invariable connection exists between negative electricity and northern polarity of the magnetic needle."

The author already quoted as above adds—

"In one of the essays (which received a prize) on the question proposed by an academy of Bavaria, in 1774, 'Is there a real and physical analogy between electric and magnetic forces: and if such analogy exist, in what manner do these forces act on the animal body?' Professor Van Swinden, of Franeker, after a long and elaborate discussion of the subject, arrived at the conclusion, that the similarity between electricity and magnetism amounts merely to an *apparent* resemblance, and does not constitute a true physical analogy; whence he infers that these two powers are essentially different and distinct from each other. On the other hand, Professors Steiglehner and Hubner maintained that both classes of phenomena are referable to the *same* agent, varying only in consequence of a diversity of circumstances. In this unsettled state the subject remained till some years after the discovery of galvanism, by which a fresh field of inquiry was opened, and a means of maintaining a large and continuous current of electricity was obtained. The first approach to a solution of the question was the publication of the views of Ritter. He asserted, 'that a needle, composed of silver and zinc, arranged itself in the magnetic meridian, and was slightly attracted and repelled by the poles of a magnet:' he also stated, 'that by placing a gold coin in the voltaic circuit, he had succeeded in giving to it positive and negative electric poles; and that the polarity so communicated was retained by the gold after it had been in contact with other metals, and approved therefore to partake of the nature of magnetism. A gold needle, under similar circumstances, acquired still more decided magnetic properties;' and, 'that a metallic wire, after having been exposed to the voltaic current, took a direction of north-west and south-east.'"

But at the period to which reference is made above, the sciences of electricity and magnetism were literally and truly in their infancy. The facts that were known pertained rather to fable than truth in numerous instances, simply because many crude theories influenced the minds of those who related or collated them. The powers of the voltaic battery were then unknown: and for many years afterwards, even to the mid-age of Faraday—say about 1837—we had no means of keeping up a steady current of voltaic electricity, by means of which a large magnetic effect could be induced on soft iron.

An able writer has remarked—"At this time, when the conditions of electro-magnetic phenomena are so well understood, it excites no wonder that the electrical experiments devised by early philosophers for settling the question led to negative results. A vicious theory pervaded electrical as well as magnetic science, and paralysed the power of investigation. The necessary function of duality, which the beautiful reasoning of Faraday has made an integral portion of electrical and magnetic study, was then unknown. Experimenters believed that either northness or southness in a magnet, or the condition of positive or negative, as regards electricity, might be capable each of an individual existence. Actuated by this doctrine, they contented themselves with bringing, successively,

each of the terminals, or, in conventional language, 'poles,' of a voltaic combination in close proximity with either end or pole of a magnet. But the magnetic extremities remained perfectly indifferent under this treatment. The north pole was not attracted—the south pole was not repelled—nor *vice versâ*. Hence the deduction was arrived at, *that between electricity and magnetism there was no necessary connection whatever*. As the direct consequence of such an experiment, the result could not be otherwise than we find it; but the wonder now is, that the true conditions of electro-magnetic development should not have been discovered collaterally, or by accident. If, instead of bringing the extremity of each terminal wire of a voltaic arrangement successively near to either pole of a freely-suspended magnet, the two conducting wires of the voltaic arrangement had been made temporarily one by contact, and the freely-suspended magnetic needle held somewhere in the vicinity of their track, then the secret reserved for the genius of Œrsted to discover, in 1819, would have been anticipated by many years."

In nearly similar language we may find the same views expressed by another writer, who remarks—

"When we call to mind the first faint glimmering, in 1774, of that light which now shines so brightly—when we recur to the essays of Van Swinden in the former period, and peruse in those essays the arguments of that professor against, and those of Hubner and others for, the identity of electricity and magnetism; thence passing on to the investigations of Beccavia, in 1777, and to those of Ritter at a later period, until, after a long interval, we reach the grand discovery of Œrsted—we can scarcely conceal our wonder, that the many brilliant thoughts and striking facts contained in the writings of those distinguished men, were not sooner seized upon by the mighty minds that shed such a flood of scientific light upon the dawn of the nineteenth century. But this wonder at the tardiness of the electro-magnetic march, until the scattered facts fell into order, and produced a science in the hands of Œrsted [or, more correctly, as we shall see, commenced with him], is turned into admiration when we consider the multitudinous array of experiments and observations science contributed from all parts of the [civilised] world, and the surprising industry which has built up so many beautiful theories, and brought the infant science of 1819–'20 within the dominion of strict mathematical demonstration, in the brief period of half a century."

Referring to our own remembrance of the early history of electro-magnetism, and writing at a time of twenty-five years later than the two preceding quotations were penned, we may still further express astonishment at the progress which electro-magnetism has made as a branch of natural philosophy, theoretical, and in its applications. Forty years ago we lectured on Œrsted's discovery of the deflection of the magnetic needle by means of an electrified wire; but, at that time, the fact was considered merely as a very interesting experiment in natural philosophy, destitute of any practical bearing. Similarly, the improved form of the voltaic battery was only just coming into vogue. Daniell's battery, which was the first that was suggested to afford an even and continuous current for any length of time, was just becoming known in scientific circles. Grove's platina or nitric acid battery was unknown for some time afterwards; as were also Smee's, Callan's, Bunsen's, or other similarly powerful voltaic arrangements. Practically, although the discovery of electro-magnetism began in 1819, its development was but commenced in 1829–'30; and its applications, for any useful purpose, were not discovered till several years had elapsed from the latter date.

Now, we consider the science, even in daily life, as one of the most important in modern knowledge. Little did Œrsted imagine, when he first noticed the deflection of the needle by a wire conveying a voltaic current, that, in another fifty years after he made that discovery, no part of the civilised world would be without wires adapted, on the principles of his early experiments, to the conveyance of messages instantaneously from one part of the globe to another, distant thousands of miles, from city to city, house to house, and from one part of a house to another. Across and beneath oceans, seas, and rivers, and on land, wires, less in section than any letter in this page, are now conveying constantly an expression of the will, wishes, and hopes or fears of mankind. Politically, commercially, and socially, India and America are much nearer the city of London, at the present day, than was Greenwich (but three miles off) thirty years ago. It would almost be an insult to the daily-acquired knowledge of our readers, to give instances of the rapidity of communication that now exists between distant places, by means of electro-magnetism in the form of the electric telegraph. In hopes of the popularity of this work extending for a few years, we may, for the purpose of future comparison, mention that New York and London are, at the present moment, in such electrical communication, that a message from either city, of a great many words in length, can be received at each in less than two minutes of time; and that, owing to the difference of longitude, a message sent from London to New York reaches the latter city several hours before it was apparently despatched, reckoning its arrival, in time, at New York rate.

If we only cursorily glance at the consequences to the affairs of men that result from discoveries hereafter to be minutely detailed, it is not egotistic in present human nature to assume, that the past history of mankind never afforded such instances of the adaptation of the powers of nature as, in our day, are matters of hourly occurrence. A war commences in India or Africa; our home government has merely to call into action the telegraph, when, in a few hours' time, forces from our Indian possessions are at once preparing for the seat of operations. Formerly six months, instead of,

as at present, as many minutes, would have been required to notify the wishes of Downing Street at Egypt or Bombay. A merchant finds his stock of cotton, tobacco, sugar, or other American merchandise in excess of, or less than, his wants; and, in a few minutes, he, residing in England, communicates his desire to a New York, Boston, or New Orleans correspondent. A sudden illness seizes a valued member of the family circle; and, in less than half-an-hour, the family physician may be called from any part of our islands. But it is unnecessary that we should further enter into the variety of interesting results that have occurred from Œrsted's discovery, and Faraday's (with his contemporaries') expansions of it. Suffice it to say, that they have made man, in his powers, resemble those of his Creator; and consequently, however he may avail himself of such results, he has become nearer to Omnipotence and Omniscience.

The subject of electro-magnetism is necessarily one of great extent and considerable complexity; we shall, therefore, proceed slowly from simple to more difficult branches of it, in order that so interesting and valuable a branch of science may become fully understood by all classes of readers. We commence with—

THE ELEMENTARY PRINCIPLES OF ELECTRO-MAGNETISM.

In the preceding pages it has been fully pointed out, that a magnetised piece of steel has a directive power, commonly called polarity. In other words, such a magnetised object takes a position, in this country, nearly north and south, subject to variations (pointed out at p. 345, *ante*) for some hundred years in respect to the variation of that variation (for we are obliged to use an apparently tautological phrase to express our meaning). Now, if the needle, as seen in the mariner's compass, be left unaffected by any other force than that of terrestrial magnetism, it will maintain this tendency to polar direction; that is, will maintain itself in the magnetic meridian at the place in which it is desired. But a wire, conveying an electric current, especially if generated by any form of a voltaic battery, if placed in certain positions in respect to the needle, will cause the latter to diverge from its polar position, and induce it to take one at right angles to that which it first occupied.

This result was first discovered, as already mentioned, by Œrsted, a celebrated Danish philosopher, at Copenhagen, in 1820. "He took a magnetic needle balanced on a pivot, as in the mariner's compass; and permitting it to arrange itself naturally in the magnetic meridian, he placed a copper wire, uniting the positive and negative plates of a single voltaic combination, in a horizontal position above the needle, and parallel to it. This being done, the needle instantly moved from its previous position, and assumed a new one to the east and west of north, according to the direction of the electric current along the copper wire. This experiment led to the first general law—"that the end of a magnetic needle which is nearest that plate of the battery-cell towards which the current is flowing, immediately moves *westward*, or to the left hand of a spectator facing the direction in which the current is moving."

Another able writer (Noad) makes the following remarks on the discovery of Œrsted:—"When a properly-balanced magnetic needle is placed in its natural position in the magnetic meridian, immediately under, and parallel to, a wire along which a current of voltaic electricity is passing, that end of the needle which is situated next to the negative plate of the battery immediately moves to the *west*. If the needle be placed parallel to, and over the wire, the same pole moves to the *east*. When the uniting wire is situated in the same horizontal plane as that in which the needle moves, no declination takes place; but the needle is inclined, so that the pole next to the negative end of the wire is depressed when the wire is situated on the west side, and elevated when [the latter] is on the east side. To assist the memory in retaining the directions of these deviations, Ampère devised the following plan:—'Let any one identify himself with the current; or let him suppose himself lying in the direction of the positive current, his head representing the copper [or negative plate of the battery], and his feet the zinc plate [positive plate] of the battery, and looking at the needle. Its north pole will always move towards his right hand.'"

Perhaps it will be still more simply stated, that if the body of the observer be placed horizontally—say on a table, with his head pointed to the north—and a current of electricity be supposed to pass from his head to the feet, over a magnetic needle presumed to be placed underneath him, with its north point corresponding with his head, then at the moment of the current passing over the magnetic needle beneath him, it will turn to his *right hand* at the north point; and, of course, the south pole will turn to the left of his feet. If, on the other hand, the current pass from his feet towards the head, then the movement of the needle will be opposite to that above described.

If the current pass *beneath*, instead of over, the needle, the motion of the latter will be the reverse of each of the preceding conditions respectively.

Any written description of this action mutually of an electrified wire and a magnetised longitudinal piece of steel, will, however, fail to give the reader a proper and exact idea of the result to which we are now directing attention. We therefore commend the following experiment as illustrative of all that has been said; and, still further, as furnishing a very simple, but effective, introduction to the science of electro-magnetism.

First, magnetise a common sewing-needle by rubbing it with a horse-shoe magnet, or, in the manner already described, by any of the methods mentioned at p. 339, *et seq.* Place the needle so magnetised on water in a basin, when, owing to the film of air surrounding the polished needle

(see p. 332, *ante*), it will readily float. Then stretch a straight piece of copper wire in such a manner that it shall be parallel to, and over the magnetised needle; that is, the needle and the wire shall both point precisely in the same direction.

Of course, the copper wire, under such circumstances, can in nowise influence the needle. But if the wire be connected with the two extremities of a voltaic cell, an effect will at once be observed.

The simplest way of effecting this, is to connect one end of the wire stretching over the needle with the zinc end of a cell, and the other end with the copper, silver, or other negative plate of the cell: and the moment this is done, the needle will diverge from its parallel position with the copper wire, right or left, according as is the direction of the current.

For example, in the following cut a needle

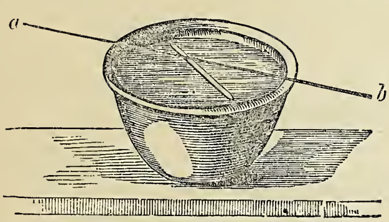


Fig. 195.—Deflection of the Needle.

is represented as floating in a basin of water, but out of its proper polar direction. *a b* is a wire conveying the current of a single voltaic cell *from b* to *a*; that is, *a* is connected with the *zinc plate* of the battery; whilst *b* is connected with the copper, silver, platina, or carbon plate, according to what form of battery is employed. We assume that the magnetised needle was at first parallel and beneath the wire, *a b*; but the moment the current from the battery is passed, then the needle is directed to the right, or east of north, represented in the above engraving.

The same result is indicated in the following cut. No. 1 shows the courses of the current

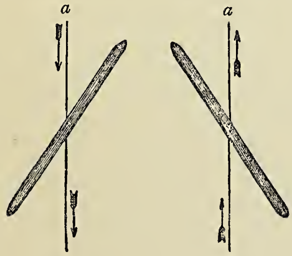


Fig. 196.

from *a* to *b*; that is, from north to south, and the consequent right-hand divergence of the north end of the needle: whilst, in No. 2, the course of the current is supposed to be from *b* to *a*; and, consequently, the divergence of the north end is to the left hand.

Now, precisely the same result as last mentioned is obtained by sending the current from north to south, *under, instead of over, the needle*; and, therefore, this experimental illustration will sufficiently verify the law of electro-magnetic action already laid down.

But in the preceding remarks, and suggested experiments, only a very partial view has been given of the relations between an electrified wire and a magnetised body. We have simply considered the action of a current of electricity conveyed in a horizontal direction on a magnetic needle poised horizontally; and, therefore, the result is one of only many that may be obtained under other, and exceedingly varied, circumstances that must hereafter require a more minute detail in respect to fact and theory.

But we may somewhat, for the present, extend the conclusions already arrived at as follows:—It will be noticed that all action on the magnetic needle, in deflecting it from what we may call its natural position, depends on the wire conveying the electric current being parallel to the direction of the needle. If it be so placed as to cross the direction of the needle—as, for example, to be in the magnetic equator, or nearly due east (by north of that point), and due west (by south of that point)—no effect whatever will result. The needle will, under such circumstances, undergo no perceptible change in direction; and only as we move the conducting wire to a position parallel longitudinally with the direction of the needle, do we notice a divergence of the latter from its polar position.

However, when the conducting wire, instead of being situated horizontally, is placed vertically, either before the northern or southern extremities of the needle, if the current from the battery move from the lower part of the wire to the upper, the adjacent pole of the needle will move towards the east; but if the current pass from the upper part of the wire to the lower, the deviation of the same pole will be to the west.

It may be briefly stated, for the present, that the action of a voltaic current on a magnetised body, and of the latter on an electric current, is operative at right angles respectively to each. In other words, an electric wire and a magnetised body tend to place each other in such a position as is represented by a mark like this—$\llcorner$.

It is of great importance that the student should fully understand the relative positions that an electrified and magnetised body take up, as resulting from their action on each other: and here we must not forget to observe that such action and reactions are equal. The magnet acts with equal force on the electrified wire as does the latter on the magnet.

Dr. Roget devised the following diagram or arrangement, to impress the effect of direction on the mind of the student:—"A B is a slip of card, on each side of which a line, *a b*, is drawn along the middle of its length, the end *a* being marked +, the end *b* —, and the centre, *c*, being

crossed by an arrow, at right angles to it. Through the centre, and at right angles to the plane of the slip of card, there is made to pass a slender stem of wood, at the two ends of which are fixed in planes, parallel to the slip of card A B, the circular discs of card marked respectively with the letters N and S, and with arrows parallel to, but pointing in a contrary direction to the one at *c*. The same marks must be put on the reverse of each of the three pieces of card, so that, when held in different situations, they may be seen without turning the instrument.

"If the line, *a b*, be supposed to represent the connecting wire (the direction of the current of electricity being denoted by the signs + and — at the ends of the line), the arrow at the centre will point out the direction in which it tends to move when under the influence of the north pole of a magnet, situated at N; or of a south pole situated on the other side, as at S; and *vice versâ*, the arrows N and S will indicate the directions in which the north and south pole respectively tend to revolve round the connecting wire in its vicinity, with relation to the direction of the current of electricity that is passing through it. It must be observed, that the poles, N S, are not considered in connection with each other, or as forming part of one magnet: their operations are exhibited singly, and quite independently of each other. The advantage of this instrument consists in its capability of being held in any situation, and thus is easily adapted to the circumstances of the fact, or experiment, of which we may wish to examine the theory." Another writer suggests as follows:—

Fig. 197.

"I would advise the student, therefore, who is desirous of analysing the apparently complex motions of magnetic needles with facility, to prepare a toy of the following description:—Cut the representation of a soldier out of cork or wood; arm him with a musket and bayonet. Assume the musket and bayonet together to be a magnet, of which the bayonet is the north pole. Assuming, furthermore, that a current of electricity passes through the soldier in the direction from head to heels, then the bayonet should always turn to the right hand."

It will be evident, from the simple experiments and remarks that have been suggested, that electricity and magnetism have, in all cases, a mutual effect on each other; and the universality of this action is a prominent point in respect to the science of electro-magnetism. We shall, perhaps, be not exactly in error, if, at this point, we impress this fact strongly on the mind of the reader, although in the following suggested experiment we shall much anticipate a more advanced portion of our subject. We, for the moment, wish to show that an electrified wire, under certain circumstances, is obedient to the influence of the magnet, although the wire, of itself, has no apparent magnetic properties.

The three designative characters of a magnetised body are attraction, repulsion, and polarity. By the following method all these qualities may be communicated to a wire conveying a voltaic current. To show this, solder to a piece of copper wire, covered with cotton or silk, a narrow strip of zinc and copper, one at each end. Then twist the intermediate wire round a pencil, so as to form a spiral, or helix, in the manner represented in the following engraving. Suspend the spiral, &c., by means

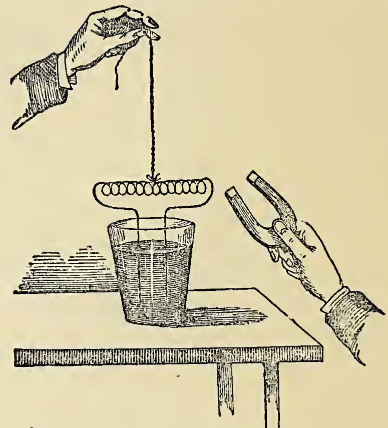


Fig. 198.

of a silk thread, and, holding this by the hand, immerse the plates of zinc and copper in a vessel holding dilute sulphuric acid. A small voltaic cell will thus be formed, and a current of voltaic electricity will be generated; the latter, circulating through the metallic helix, or spiral, will so act upon it as to *make it magnetic.* In other words, it will acquire a polar direction just like that possessed by a magnetised needle; and, still further, if a horse-shoe or bar magnet be presented to its two extremities, all the phenomena of attraction between dissimilar poles, and of repulsion between two similar poles, will be exhibited, just as if the copper helix were a magnetised needle.

This very simple, but highly instructive, experiment at once proves that an electrified wire, under certain invariable conditions, acquires at once magnetic properties. It also explains why an electrified wire can cause the divergence of the magnetic needle from its ordinary position; for we see plainly that, by the last experiment, an electrified wire can be made to assume all the properties of a natural magnet or loadstone, or those of an artificial magnet.

It is not too much to say, that the discovery of this fact, in a scientific point of view, is amongst the most important that has been made during the last two centuries—in fact, since Newton first demonstrated the laws of gravitation. When dealing with the causes of terrestrial magnetism, at p. 353, *ante, et seq.*, we mentioned that no theory of magnetic action could be complete independent of a collateral

implication of electricity. Our readers will, therefore, at once perceive the reason that led us to defer a full inquiry into the causes and theories of magnetism, until we had the opportunity of explaining electro-magnetic phenomena. In part, this was anticipated when we entered into a description of Barlow's electro-magnetic theory of the cause of terrestrial magnetism, at p. 355, *ante*. But we have yet much to explain before the direct connection between the two—at first, apparently, diverse—forces will be fully perceived.

Having thus shown that an electrified wire causes the divergence of a magnetic needle, and that the former can be proved to have magnetic properties whilst, under certain conditions, conveying an electric current, we proceed to illustrate these facts under a much larger variety of aspects.

It has already been stated, that the magnetic needle acts on the electrified wire as the latter acts on the needle; and, as this is an important point in relation to the construction of many kinds of electro-magnetic apparatus, we must enter more fully into this question before proceeding further. "The influence of the conducting wire on the pole of a magnetic needle, is of necessity accompanied by an opposite action of the magnet on the wire. For instance, when the current impels the pole from left to right, the pole impels the wire from right to left, and *vice versâ*. These effects are, of course, diminished by the influence of terrestrial magnetism upon the needle, which may, however, be obviated by so disposing a magnet in the vicinity of the needle as to counteract the effect of the earth's magnetism; or by employing an astatic needle"—that is, one in which two needles are used, placed one over the other, with their opposite poles adjacent, so that the directive or polar influence is neutralised.

The same writer remarks—"It is a curious fact, that although the conducting wire exercises so great an influence on the magnetic needle, yet, when a powerful magnet is presented or applied to a conducting wire connected with a voltaic multiplier, no difference of effect is perceivable. From which it may be inferred that magnetic influence cannot retard or accelerate the passage of a voltaic current along a conducting wire. But the latter has been found to possess the attractive powers of a magnet while traversed by the current; for, under such circumstances, iron-filings presented to the wire (no matter of what metal it may be composed) will be powerfully attracted, and adhere thereto; but on cutting off the current, the attractive influence ceases, and the filings drop off. Ampère remarked, that when two conducting wires were parallel, and currents flowed through each in the same direction, they attracted one another; but when the currents passed in contrary directions, they were mutually repelled, the repulsive and attractive forces of the currents being equal."

From what has been previously stated, it therefore results that the action of a magnetised body, and an electrified one, is mutual, although not necessarily equal; because the amount of the force in one case may, according to the will of the operator, be in excess on either side. Moreover, it is barely possible, dealing with three separately acting forces—namely, that of the voltaic current, the directive force of the magnetic needle, and the inductive action of the magnetism of the earth, already so fully explained—that we can experimentally so manage these three forces as to render each mathematically equivalent in value to the rest.

Having established some elementary principles of electro-magnetism, especially the mutual action of electrified and magnetised bodies, we shall next turn to some practical points, attention to which will ensure success in the experiments that will hereafter be suggested. An old saying holds that a bad workman complains of his tools; and, in electro-magnetic investigations, there is great reason for care in minute points of manipulation.

General Directions for conducting Electro-magnetic Experiments, or Research.

With proper care, no branch of experimental inquiry can be more easily, readily, or cheaply carried on than that of electro-magnetism. Within fifteen years of the earliest discovery of this branch of science, we were enabled, out of a mere boy's pocket-money allowance, to repeat all the leading experiments that illustrate the phenomena of the science. At that time the purchase of philosophical instruments was a question of great expense; and no branch of scientific research could then be carried on except at great cost; and, consequently, only by those who possessed ample private means, or who were connected with some scientific institution. Fortunately, we were at least in the latter condition. An intimate friend of Faraday, Charles Woodward, F.R.S., took so much interest in our early attempts as to place ample instrumental arrangements at our disposal. We do not hesitate thus to acknowledge, in the most grateful manner, such kindnesses, especially as, in so doing, we follow the example of Faraday himself; who, in his *Researches*, owns that, to his assistant, Mr. Anderson, much of his success as an experimentalist depended. From our personal knowledge of each, we may safely remark, that in all such matters they were mutually dependent; for, on more than one occasion, we have known Faraday absolutely to decline the use of apparatus proffered to him, until it had undergone the careful trial or inspection of his highly-esteemed assistant.

Chemical, and all other branches of experimental philosophy, essentially depend on *manipulation*; that is, an ability, on the part of the experimentalist, to fulfil all the conditions requisite to success. Some men are exceedingly apt in such matters, whilst others are as equally inapt. At the lecture-table, one will prove, to the complete satisfaction of all present, that a stated fact is a real fact. As Faraday remarked, if he said that a stone falls to the ground by virtue of gravitative force, he did not leave the

fact unshown, but proved it by dropping the stone. Hence his great success in public expositions of science. No person who saw and heard him, if possessed of common sense and intelligence, could leave the lecture-room where Faraday had been speaking, without knowing at least *something*, if not *all*, of what had been said.

It is more than probable that these pages may fall into the hands of many who may be desirous of enlarging, in public, on the subjects of which we are writing; and it is needless to add, that experimental illustration is of the utmost value under such circumstances. Some of our readers, again, will be desirous of entering into experimental inquiries of the subject in hand; whilst others, out of mere intelligent curiosity, may wish to repeat, personally, the experiments that have been, or are to be, suggested. In any case the following practical hints cannot fail to be of service. We shall divide them into separate headings, so as to simplify and impress the chief points of importance.

Sources of Electricity.—The characteristic fact in connection with the production of electro-magnetic phenomena, is, that the greater the *quantity* of electricity, the greater is the resulting action on a magnetised body. Now, the electricity produced by a common cylindrical or plate electrical machine is so trifling, comparatively speaking, that great difficulty exists in effecting any action thereby on the magnetic needle. Faraday conclusively proved, that a wire each of zinc and platina, less than an inch in length, afforded a greater *quantity* of electricity than a powerful flash of lightning. Now it is quite unnecessary for us to remind even the unscientific class of our readers, that the most powerful electrical machine which has yet been constructed can afford only the most minute fraction of the electricity evidenced by a flash of lightning. It may still more impress the fact, if we state that a half-crown, and a piece of zinc of the same size, placed one on each side of the tongue, will excite sufficient electricity, in quantity, to send a message by the Atlantic telegraph from Ireland to America. The action of such a small battery would not exceed, on the tongue, that experienced in drinking a little porter from a pewter or silver pot. On the other hand, a flash of lightning would afford far too little electricity, in quantity, for such a purpose, although it would instantly destroy several human beings, houses, &c., &c., by its action in another way.

The fact is, the electricity of the thunder-storm is highly intense; that is, it can force its way through such bad conductors as air, water, wood, &c., &c. But the electricity set free by chemical action, as by the zinc and platina wire, or the half-crown and zinc just suggested, has little or no power of overcoming the obstacles above named. Yet, if such a produced current travel over a good conductor—as, for example, a copper wire—its magnetic effects are very great.

Hence it was that the discovery of electro-magnetism was so long retarded. Until the close of the last century, no means were known of exciting a quantity of electricity. Our forefathers in science had merely the electrical machine made of glass, and excited by the friction of rubbers on the surface of that material. It was not till Volta produced his "pile" (successively improved by Cruikshank, Babbington, Wollaston, Daniell, Grove, Smee, and others) that we became possessed of means by which we could produce sufficient of electricity, in respect to quantity, as would afford electro-magnetic phenomena; and, as already shown, it was reserved for Œrsted, in 1819 or 1820, to adapt such means to show the mutual relationship of an electrified and a magnetised body.

It will be needless for us here to enter into a description of all or many of the forms of voltaic arrangements that may be employed for electro-magnetic experiments. In the great majority of instances, a plate of zinc amalgamated by first dipping it into a little sulphuric acid, and then rubbing it with mercury, together with one of copper—each having a copper wire about two feet long soldered to it—will be sufficient. The two plates are immersed in a dilute solution of acid, formed by adding one of sulphuric acid to ten parts of water by measure. A still better arrangement—and one to be preferred to all others by the beginner in the science—is a single cell of Smee's platinised silver battery, which may be purchased of a sufficient size for 5*s.* of any philosophical instrument-maker, optician, or practical chemist in any town. It is charged with the acid mixture just named; and is so easy of management, that a lad, after a first instruction, may employ it with ease and certainty. The constant battery of Daniell, and the nitric acid batteries of Grove, Callan, and Bunsen, are much more complex in character; but any of the three latter are best capable of producing the most powerful electro-magnetic effects, so far as the excitement of great magnetic powers are concerned. But of this we shall deal more fully in the proper place. All phenomena whatever, in electro-magnetism, may be conveniently studied by aid of a single cell of any form of battery; but, as already stated, Smee's is the best for the beginner, and the most convenient for all purposes. Whatever battery be employed, the solution of acid next the zinc should be strong; and, to prevent waste of that metal, it should be repeatedly amalgamated in the manner just pointed out.

Next in importance to the question of battery, is that of *connections*; by which we mean those arrangements that are employed to connect one piece of apparatus with another. If, as is usual in electro-magnetic experiments, only one or two battery cells be employed, then it is absolutely necessary that the connections should be as accurate as possible, otherwise the electric current will be impeded, or, perhaps, entirely stopped in its passage. The most accurate and complete method of forming a connection between two metallic bodies, is that of soldering; for by that the different parts are, metallically speaking, made one. Thus, if a wire be soldered to a plate, it follows that the two must be in absolute metallic contact. A more usual, and frequently a more convenient, method—because it allows of ready change—is that of binding-

screws. These are obtainable, at a cheap rate, of the instrument-maker; and may be readily affixed by soldering to a plate, or any other metallic object. A wire, inserted into a small hole in the binding-screw, is held tight by the latter being turned down on it. The numerous shapes given to these articles precludes us illustrating them ; but they are so easily obtained as to render that unnecessary.

Another method, and one that is remarkably cheap, ready, and efficient, is that of *mercury cups;* and, next to soldering, this plan gives the best connection that can be made. Any hollow body—such as a small cup of wood, glass, or iron—is filled with mercury ; and into this are dipped the two wires that it is desired to connect. The ends of the wires should be first amalgamated by dipping them, for an instant, in a little nitric acid, and then in mercury. The ends are then washed and wiped clean, and afford an excellent means of connection between two pieces of apparatus by means of wires. A piece of mahogany, four inches square and an inch thick, having four separate holes half an inch each way drilled into it at equal distances, is an exceedingly handy form of connection, especially when it is desired to repeatedly change the direction of the current. Of course, each hole is filled with mercury ; and the wires proceeding from the battery can be connected with those from the apparatus in use, in any direction that may be desired, the direction of the current being, of course, readily changed when needful.

The experimentalist should provide himself with a quantity of the best annealed copper wire, of No. 16 gauge, for connecting the battery cell with apparatus; and also some of about 22 gauge—the latter, from being thin and pliable, answering well for *short* connections. It must be borne in mind, that *the longer the connecting wire, the greater is the resistance it affords to the passage of the voltaic current.* Hence, in all cases in which a single cell of voltaic battery is used, the connecting wires should be as short as possible between the battery and the apparatus. Too thin a wire, also, affords a resistance to the passage of the current ; but either of the sizes already named answers well with a single cell for most electro-magnetic experiments. Exceptions to this will be noticed in the proper place.

The ends of wires, if not amalgamated, should be kept clean by rubbing them with sand-paper. Most of the failures that arise in the lecture or private room, in connection with all electrical experiments, occur almost constantly from want of attention to this point. We might give multitudes of illustrations of this fact, that have come under our notice during the last thirty years. Even gold and platina wires, were they used for connecting purposes, would gradually become superficially coated with non-conducting substances. But they are rarely used, copper being almost the only wire, with the exception of brass, that is employed in all experimental inquiries. Now, a copper wire is scarcely polished, before, under all ordinary circumstances, it becomes covered with a film of oxide, that, acting as a non-conductor, reduces the amount of electricity passing from a battery to apparatus. One of the chief reasons that have prevented the application of electricity for motive purposes, in regard to electro-magnetic arrangements, has been the difficulty of keeping surfaces of conducting wires, or other objects, clean from oxide, or various non-conducting matters. Some years ago, we had committed to our charge, for experimental purposes, an electro-magnetic motive machine, *said* to be of one-horse power. In an unclean condition, even fifty cells of Grove's battery, with platinas $8 \times 4\frac{1}{2}$ inches, could not cause it to work ; whilst, when cleaned, four of the cells made it work rapidly. In small apparatus precisely the same rule holds good ; and if one cell alone be employed, the matter becomes still more important, because such a battery has far too little intensity to overcome obstacles of the kind to which we are now drawing attention. Some years ago we had conferred on us the honorary office of curator of a laboratory, containing every variety of electro-magnetic apparatus used for illustrating the principles of the science, and that will be subsequently described. Not one would work even with the aid of twenty large cells of a Daniell's battery ; but, by the aid of a little mercury, sand-paper, and patience, any, or all of them together, were made to work with a *single* cell of the same arrangement.

The quantity and consequent electro-magnetic power of a single cell, presuming that the preceding points have been carefully attended to, will depend on the size of its plates, the strength of the exciting acid, and the proximity of the plates to each other. Thus, in respect to the first point, if a Smee's single cell be placed in a trough, and the latter be half filled with dilute sulphuric acid, the power of the cell, in respect to quantity, will be double when so much acid liquid is added as will double the active surface of the plates. Consequently, the amount of electric energy brought to bear in any experiment, may, under ordinary circumstances, be regulated to any desired extent. Of course, we are now referring solely to such experiments as embrace the use of only short connecting wires, or those in the apparatus—say not exceeding a few feet. If, as in inductive experiments (to be hereafter described), in which several hundred feet of wire in coils are employed, the intensity of one cell will not be sufficient, in certain cases, to overcome the resistance of the wire, a number of cells must be employed.

The varying effects of the size of plates of a battery, in respect to the spark and shock obtained from short and long lengths of wire, or ribbon coil, are exceedingly well illustrated by some experiments made by Dr. Noad, and published by him many years ago. We have verified them by repeated trials ; and although they somewhat anticipate other portions of our subject (that is, they are chiefly connected with electro-magnetic induction), still they will illustrate what we are now urging—that the size and number of plates of a battery used in electro-magnetic experiments, must be regulated ac-

cording to the length and size of the conducting wires to or on the apparatus. Dr. Noad observes—

"On repeating the beautiful experiments of Faraday [to which we shall hereafter draw attention], I was induced to try the effects of strong and weak electrical currents on a long flat coil, of considerable breadth of surface. For this purpose I took two sheets of thin copper, each four feet and a-half long, and twenty-six inches wide; and, cutting them into ribbons one inch wide, I soldered all the lengths together, and formed the whole into a single coil, with list intervening. I thus had a continuous coil of copper ribbon, two hundred and thirty-four feet long. At the commencement of the coil, and at intervals of twenty-five feet through its whole length, wires were soldered, which projected about two inches, and supported small cups to contain mercury, By this arrangement I could send the current through what length of ribbon I pleased, from two hundred and thirty-four to twenty-five feet; and, by the aid of the mercury cups, I could examine the effect produced on one part of the wire, by the action of an electrical current sent through any other part. In describing some of the experiments made by this coil, I shall distinguish the cups by figures, indicating their position on the coil, thus:—

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
corresponding to	25.	50.	75.	100.	125.	150.	175.	200.	234.	feet.

"1. When communication was made with the positive end of a pair of plates, contained in a pint cup, and excited by dilute sulphuric acid, and cup 1, and the wire from the negative end, dipped in succession into 2, 3, &c., to the end of the arrangement, the spark and snap increased in intensity to 4; at 5 it appeared the same, and afterwards went on decreasing to 10, when the spark was not nearly so large, nor was the snap nearly so loud. The maximum effect, therefore, seems to be produced with the battery when the current has increased between 75 and 100 feet.

"2. When a half-pint battery was employed, no difference in the size of the spark could be perceived in 4, 5, 6, 7, 8; but it was larger and brighter in these cups than in 2, 3, and 9, and 10, in which it seemed about the same. With a pair of plates containing about a fourth of the surface of metal, no difference in size, or appearance of the spark, could be perceived throughout the whole arrangement after cup 2, being as bright at 10 as at 3.

"3. When a pair of plates, each two inches square, was employed, the spark seemed brighter at 9 and 10 than either at 4, 5, or 6. With a pair of one-inch square plates the difference was more marked. With a pair half an inch square, it was feeble in 2, 3, 4, after which it went on increasing; and at 10 it was much larger. With a pair of quarter of an inch, I several times heard a slight snap accompanying the spark in the last three cups; but the sparks produced in the first six cups were decidedly smaller and less bright.

"4. A pair one-eighth of an inch square was then tried, and sparks were produced in all the cups; feeble in 2 and 3, but in 7, 8, 9, 10, bright; largest and brightest in 10.

"5. Strips of copper and zinc half an inch long, and one-tenth of an inch wide, were immersed in acidulated liquor, and connected with the coil; sparks were obtained in all the cups, bright in 8, 9, 10: the strips were then cut in half; and, by rapidly breaking contact, sparks were obtained in 5, 6, 7, 8, 9, 10; I could only occasionally get them from 4; and not at all from 2 and 3. The strips were then reduced to about one-sixth of an inch long, and one-twentieth wide; in 9 and 10 I obtained several sparks, but could get none from any of the other cups.

"6. A large calorimotor [or single cell, exposing several square feet of surface], recently cleaned, and highly excited with nitrous acid, was then tried; the brightest and loudest spark was at 2; the snap was very loud, and could be distinctly heard in a room, at the bottom of a flight of stairs, the door being shut, and also the door of the room in which the experiments were made; it was as loud, every time contact was broken, as the explosion from a quart Leyden phial; the sparks were very vivid, and evolved copious fumes of mercury: these effects rapidly diminished as the connecting wire approached the termination of the coil, and, at 8, 9, 10, the sparks were not more brilliant, nor louder, than those produced by the half-pint battery."

We learned more, in respect to the regulation of quantity and intensity for electro-magnetic experiments, by the repetition of the precedingly-related experiments by Mr. Noad than from any other source. It is true that he employed the old and imperfect kinds of battery; but that fact does not in any way lessen the value of the results he obtained, because the source of power was identical in nature, although not in degree, in respect to obtaining each result. His object, as before mentioned, was to obtain an insight into the inductive effects by the use of various-sized plates; but it will be evident, that the results so arrived at are equally applicable to illustrate the point we have in view.

The experimenter should furnish himself with a quantity of copper wire, covered with either silk or cotton, the latter answering for all ordinary purposes. The greater portion of electro-magnetic experiments require wire twisted into coils, and hence metallic contact of one convolution with another one adjacent must be avoided. For all ordinary purposes, No. 16 and No. 22 wire will be alone requisite. Covered wire may, with all other needful matters, be obtained, at a cheap rate, of the philosophical instrument-makers.

Mercury is of constant use, for the purpose of making and breaking contact, its fluid and conducting characters admirably adapting it for those objects. But, to be of service, it must be clean, and quite free from admixture with lead or other metals, for a minute portion of these will prevent mercury from presenting the round edges that are required. Many plans have

been suggested to clean this metal. Of course, the best is to distil it, which may be done in an iron or porcelain retort, receiving the mercury as it runs over in a clean earthen vessel. But this is a troublesome method, and requires some care in manipulation. As all the metals likely to occur in mercury are oxidisable in cold air, whilst mercury is not, it has been recommended to put impure mercury into a bottle, and agitate it violently for some time. Gradually a black powder separates, which consists of the impurities of the mercury. The latter may then be poured off into a piece of chamois leather, shaped like a bag. By twisting the loose portion of the bag tight, the mercury will be forced out in minute streams or globules, and these at once coalesce. Another method is, to pour the mercury, after agitation, into a cup of porous wood, and to exhaust the air from beneath the latter by means of an air-pump, the cup of wood being fixed on the neck of a glass vessel, the lower end of which rests on the plate of the pump. In doing this care must be taken that none of the mercury flows on to the brass plate, or into the hole by which the air is exhausted; for if that occur the pump will inevitably be rendered useless. On one occasion we saw a valuable pump completely spoilt by such an accident.

We generally keep all mercury that has been used for electro-magnetic experiments in a stoppered glass bottle containing a little nitric acid and water. Before requiring the mercury the two liquids should be well agitated together. As much mercury as may be wanted at a time is then poured out, well washed with water, and dried, when it will be fit for use. This is the simplest and easiest method of always having clean mercury ready.

A common occurrence with beginners in electro-magnetic experiments, is that of knocking over the vessels containing mercury, through forgetting the great weight of the metal. It is therefore best that all cups and other arrangements employed to hold it should be broad and shallow, so that the centre of gravity of the vessel be low. The bottoms of broken glass bottles, an inch and a-half wide, are useful to hold mercury. Pieces of mahogany, two inches square and an inch deep, with a half-inch hole bored in the centre, form excellent vessels for many purposes, and are both cheap and lasting.

Before concluding these practical hints, we may add a piece of advice that may be of serious importance to our readers. In many experiments, the inductive influence of the magnetism produced by electric agency is very great, and, consequently, if a watch be brought near to the apparatus, it may be greatly injured by the production of magnetism in the steel works. We have had three or four watches spoilt by this; hence it is desirable to avoid any risk by removing the watch from the pocket, beyond the influence of magnetism. Another source of accident to watches, rings, &c., is that of accidentally placing them on small globules of mercury, that may be, and generally are, despite all care, scattered over the table on which the experiments are conducted. On one occasion, having thus placed a gold watch on a table, the case was completely destroyed by mercury thus communicated.

VARIOUS ELECTRO-MAGNETIC PHENOMENA.

We have already sufficiently pointed out that a wire conveying a voltaic current has magnetic properties, and, consequently, affects magnetised bodies, as shown in the divergence of the needle on passing a current over or under, but parallel to it; and by the attraction and repulsion of a coil, as illustrated by Fig. 198, at p. 378, *ante*. We shall now suggest a variety of experiments; and describe several forms of apparatus that have been devised to impress the facts of the science on the mind of the student.

If a wire carrying a voltaic current be laid flat on a table, and some iron-filings be sprinkled over it, the magnetic characters of the current will at once be noticed; for the filings will arrange themselves in a similar manner to that which would be seen if they surrounded a bar magnet. So soon, however, as the current is stopped in its passage through the wire, all sign of magnetism ceases, and the filings fall off. On restoring the current, the magnetic effect will at once be perceived.

A very simple method of showing the magnetic character of the sides of a coil conveying a current, and resembling, in principle, that described at p. 378, *ante*, and illustrated by Fig. 198, but differing in form, may be made as follows:—

A circular copper wire, having its extremities passed through a cork, is to have one of them soldered to a small plate of zinc; to the other, a small plate of copper. The arrangement, as will be seen, constitutes a simple floating voltaic combination. It can readily be excited by floating it in dilute sulphuric acid; and will, of course, be free to assume any directive tendency. The letters C and Z denote the copper and zinc plate of the cell; and the arrows show the direction of the current. On causing either pole of a magnet to approach this little apparatus on different sides, the floating combination will manifest various phenomena of attraction and repulsion, all explicable on the principles already enunciated. The instrument admits of being rendered still more delicate by covering the wire with some non-conducting substance, and reduplicating the number of turns. Such an improved instrument is represented on the following page.

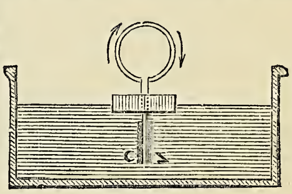


Fig. 199.

The magnetic characters of wires in the act of transmitting electric currents, may be also readily demonstrated by means of forms devised by Ampère, and represented in the following

cut. The forms of apparatus in question may be delicately suspended, or converted, by means of pieces of cork and metallic plates, into float-

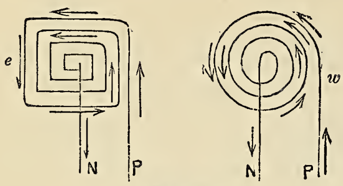


Fig. 200.

ing arrangements, similar in principle to the one just described. Thus managed, the flat spirals will always arrange themselves in the direction of north and south ; one definite side of the coil always corresponding to one invariable direction of the electric current. In conformity with principles already enunciated, each coil of the flat helices may be regarded as a separate magnetic pole ; therefore it will readily be seen, that, in proportion as the number of coils is increased, so, in equal measure, will be the amount of directive tendency. The letters N and P indicate connection with the negative or copper plate, and the zinc or positive plate of the arrangement ; whilst *e* and *w*, respectively, show the east and west *ends* of the coils, the *sides* presenting the magnetic phenomena.

But, in all the preceding experiments, we have considered either the wire or magnet at rest, and have only noticed motion in one of them. Until the discovery of Faraday—presently to be described—it was considered, "that a force, at one time attractive, and at another time repulsive, acted in straight lines between the magnet and the conducting wire. The opinion, however, soon gained ground, that such numerous attractions and repulsions, ever varying, were suggestive of rotation." Faraday succeeded in showing that an electrified wire would rotate round a magnetic pole ; and that a magnet would rotate round an electrified wire. The apparatus he arranged for this purpose is represented in the following cut.

The vessel is a cup of glass or wood, holding mercury. *n s* are the two extremities or poles of a bar magnet, attached loosely at *s* to a wire *c*, at the bottom of the vessel, in such a manner as that the magnet may be free to move, as on a pivot. *a b* is the conducting wire of a single voltaic cell, attached to the negative plate ; whilst *d* is a wire attached to the zinc plate of the battery. So soon as the connections with the cell are completed, the north pole, *n*, of the magnet will begin to rotate round the wire, *a b*, and continue to do so as long as the current passes.

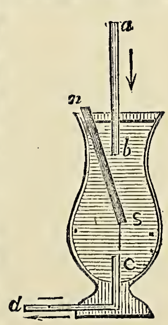


Fig. 201.

The converse of this rotation may be exhibited by a similar piece of apparatus, also invented by Faraday, and represented in the annexed cut. In this, *n* represents the north pole of a bar magnet, *fixed* in the centre of a cup holding mercury. *a b* is a movable wire, so hung on one proceeding from the negative plate of a cell, as shall permit it to move freely ; and the zinc plate of the cell is attached to *d* by a wire. On the connection being complete, the wire, *a b*, will immediately commence to rotate round the north pole of the magnet, *n*.

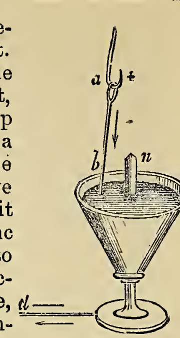


Fig. 202.

This beautifully-devised experiment of Faraday at once opened an entire new field of inquiry, and stimulated philosophers to try a great variety of experiments, and to devise new apparatus illustrative of the constantly-fresh arising facts. Some of these were of a very complicated character, and required great care in their manipulation. But they were all intended to illustrate in one way or another the mutual affections of an electrified wire, and a permanently magnetised body, although the latter condition was not essential, because an electro-magnet, of course, philosophically speaking, might, so long as it is influenced by the electric current, be considered as a substitute for a permanent magnet. But practically speaking, an electro-magnet is not suitable for the purpose of such illustrations, because it introduces necessarily an element for consideration which would necessarily prevent the student from perceiving the exact relationship which subsists, in the abstract, between an electrified wire and a magnetised body. In this and the preceding illustrations or descriptions of the elementary doctrines of electro-magnetism, therefore, the use of a permanent magnet, either in the bar or horse-shoe form, has been always understood as to be employed. The apparatus must be of great delicacy in most cases, because the bar, or horse-shoe magnet, generally, to save weight and bulk, is usually small. The difficulty of keeping up the connections is great, because the points of the wires are apt to get dirty by oxidation, and the mercury of the mercury cups will constantly be thrown out, if any but a very moderate battery power be employed.

The following is a description of an apparatus (contrived by Messrs. Watkins and Hill, now Eliot Brothers, of London), which we quote from Dr. Noad. From inquiries we find that this form of apparatus has almost been forgotten by the instrument makers.

"In order to obviate the necessity of employing so much quicksilver, which, by the resistance it offers to the revolution of the magnet, greatly diminishes the velocity of the rotation, the following apparatus was devised by Mr. Watkins. It exhibits the contrary poles of two magnets rotating about two electrified wires. These flat bar magnets are doubly bent or curved in the middle of each, and have under the inverted part of each, an agate cup

fixed, by which it is supported upon an upright pointed wire, affixed in the basis of the apparatus, and upon which it turns round as upon an axis. Above the agate cups cisterns to hold mercury are also found. Two circular troughs, to contain mercury, are supported upon a stage affixed to the basis, having holes in their centres, to allow the magnets to pass through them. A bent pointed wire is affixed into the cisterns of each magnet, the ends of which dip into the mercury contained in the troughs upon the stage ; and through the sides of the trough wires are passed, entering into the mercury contained in the troughs, and bearing at their ends other cups to hold mercury. To steady the motion of the magnets, wire loops are affixed to them, which embrace the upright pointed wires on which the magnets rest. A hollow pillow is firmly affixed to the stage, in which a bent wire, supporting another cross wire, is inserted ; and is capable of being raised or lowered, and secured at any required height, by a binding-screw. The two ends of the cross wire are bent downwards and pointed, and made to enter the two small cisterns affixed upon the magnets. A third cup, to contain mercury, is also provided at the top of the cross wire ; and a communication being made with the battery, by means of the uniting wires dipping into the mercury in the cup, the wire from the positive end of the battery being placed in the upper cup, and the wire from the negative end in each of the lower cups, the magnets will begin to rotate in opposite directions, and those directions may be reversed by changing the situations of the uniting wires. Two cells should be here employed, in order to make both the magnets revolve with the desired velocity ; and attention must be paid, when using two batteries, that the currents of electricity flow in the same direction, otherwise the phenomena of the revolutions of the magnets in contrary directions will not take place, but they will both revolve in the same direction."

By another and very ingenious contrivance of Ampère, the plates forming a small voltaic cell may be made to rotate round the poles of an upright bar magnet. The cell consists of a cylinder of copper, about two inches high, having within it a smaller cylinder about one inch in diameter, represented in the following cut, and a section in that on the right hand.

"The two cylinders are fixed together by the larger having a hole cut in its centre from below, the size of the smaller cylinder, leaving a circular cell, which may be filled with acid. A piece of strong copper wire is fastened across the top of the inner cylinder, and from the middle of it rises, at a right angle, a piece of copper wire, supporting a very small metal cup, containing a few globules of mercury. A cylinder of zinc, open at each end, and about one and a-half inch in diameter, completes the voltaic combination. To the latter cylinder a wire, bent like an inverted U, is soldered at opposite sides ; and in the bend of this wire a metallic point is fixed, which, when fitted in the little cup of mercury, suspends the zinc cylinder in the cell, and allows a free circular motion. An addition to this apparatus was suggested by Mr. Barlow, and constructed by Mr. Newman, who

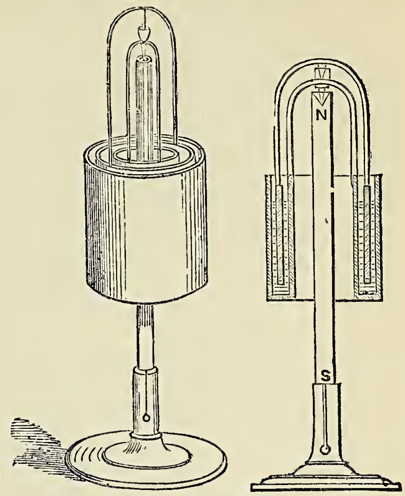


Fig. 203.

fixed an additional point, directed downward from the central part of the stronger wire, which point is adapted to a small hole at the top of a bar magnet. When the apparatus with one point only is charged with diluted acid, and brought into communication with the end of the magnet, placed vertically, the zinc cylinder revolves in a direction determined by the magnetic pole which is uppermost. With two points the copper revolves in one direction, the zinc in a contrary one. The magnet employed in the experiment requires to be powerful."

This apparatus very well illustrates the action of the respective forces on each other. Care must be taken that too much acid is not put into the cell, lest by the revolution it may be ejected. Indeed, this occurrence often causes some difficulty in carrying out the experiment successfully, as the connections get oxidised, and, consequently, become non-conducting. As pointed out in the practical hints already given, the success of all such experiments essentially depends on clean and bright connections.

A very simple apparatus, that may easily be constructed, shows a form of electro-magnetic phenomena of a similar nature to what has already been described. It is shown in sections in the following cut :—

a is a flat mahogany board or foot, about twelve inches long, and four broad. In the centre, at *b*, it is hollowed out to form a small trough, that is filled with mercury. *c* is a brass rod, fitted in the board, and bent round, with a hook at *d*, from which is suspended, at *d*, a wire, *e*, the other end of which rests in the mercury in the trough, *b*. The two wires, from a single voltaic cell, are represented by *p* and *n*. Hence the current will travel from *p* to *n*, or *vice versâ*, through the mercury, the suspended wire, and the rod, one wire being inserted in the mercury, and the other attached to the rod. Of course, under such circumstances, no motion whatever

will take place ; but on placing a horse-shoe magnet on the board, *a*, so that its pole may be

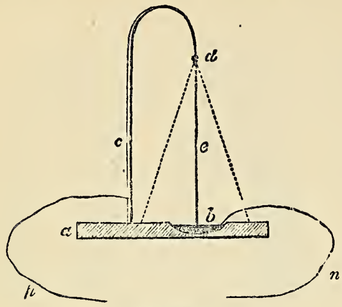


Fig. 204.

respectively on each side of the wire, the latter will at once leap out of the mercury trough. By so doing it breaks the continuity of the current, and so ceases to be electrified. But, by gravitation, it once more falls into the mercury, becomes again electrified, and is again ejected. A constant series of such oscillations may thus be kept up. The direction will be in one of the dotted lines, according to the direction of the current or position of the poles of the magnet ; and either may be reversed accordingly. In trying this experiment, it is well to amalgamate the top of the wire, *e*, that enters into the trough, *b*. This is easily done by dipping it for a moment into nitric acid, and then into mercury. As previously stated, this method is generally required to maintain good contact of wires with mercury in all electro-magnetic experiments.

A modification of this experiment was made by the late Mr. Barlow. It acts on precisely the same principles as the last one ; but instead of a jerking motion, a circular one is obtained. In fact, we may regard the wheel we shall mention, as made up of an infinite number of wires, or radii, proceeding from a common centre, instead of being suspended from a hook, as shown in our last engraving. To construct this arrangement, cut a circular wheel out of thin sheet copper, and through its centre solder an axle of

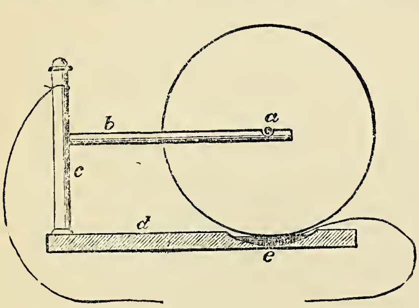


Fig. 205.

copper wire, as at *a*, Fig. 205, so that it may freely turn thereon ; and supported by a brass arm, *b*, which is to be fixed to an upright, also of metal, *c*. This may stand on a wooden foot, hollowed out at *e*, as in our last arrangement ; and the rim of the copper wheel should just touch some mercury contained in the trough, *e*. One wire of a battery is to be attached to the upright, *c*, and the other is to be immersed in the mercury in the cistern. On placing a horse-shoe magnet, with its poles resting on the foot, on each side of the wheel, the latter will begin to rotate, and will maintain its motion so long as the current of electricity passes.

If, in place of making the circular plate continuous, as in the preceding engraving, it be cut in a stellar form, so as to present successive points at its rim (as shown in the annexed cut), the experiment not only will be varied, but a spark will be produced as each edge leaves the mercury, just as is observed in using the vibrating needle, illustrated by Fig. 204, *ante*.

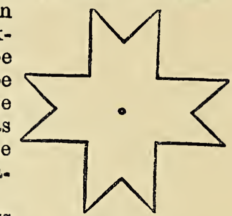


Fig. 206.

So many instruments have been devised to illustrate motion caused by the mutual action of magnetism and electric currents, that to enumerate them all would be to make this portion of our work little different from a catalogue of scientific instruments. At first sight, most of these present many difficulties, that the tyro in science may have much trouble in getting over ; but if the principal doctrine of electro-magnetism be kept carefully in mind, all difficulty will gradually disappear. In fact, electro-magnetism, like every other branch of science, has its "alphabet," which must be mastered before progress can be made by the student. We have already described and illustrated the fact that an electrified wire may be made to rotate round a permanent magnet, and, *vice versâ*, that a permanent magnet may be made to rotate round an electrified wire ; and it is to impress on the mind this fact that so many different instruments have been invented. An interesting illustration of the rotation of conducting wires, in the form of a helix, round the poles of a horse-shoe permanent magnet, is shown by the following arrangement. It consists of a horse-shoe magnet, firmly screwed to a wooden basis, or support ; two heliacal coils of copper wire, having slender bars across their tops, with needle points in their centres, turning in conical holes, drilled in the ends of the magnet, and above the points, two small platinum cups, to hold a globule of mercury in each. Two wooden cisterns are attached by screws on the lower parts of the magnet, having bent arms fixed to them. To the lower ends of the heliacal coils are soldered slender pointed wires, bent so as to enter slightly into mercury, placed in the two larger cups, mercury being also placed in the small cups. A brass standard affixed to the basis of the apparatus, has a forked piece attached to it, with two points descending into the two platinum cups upon the tops of the coils : and there is also another cup placed upon the forked piece to contain mercury. The voltaic circuit is completed by placing wires in the

mercury contained in the small side cups, and connected with the copper plate of the battery: and other wires communicating with the zinc plate of the battery are placed in the cup at the top of the apparatus. When the electric current flows through the apparatus, the heliacal coils revolve rapidly in opposite directions; but on changing the disposition of the connecting wires, the revolutions of the coils will be reversed. The points of the wires must be very clean and amalgamated, and the mercury in the cisterns and cups kept free from dirt. Instructions for this have been given in the practical hints previously suggested.

From all these experiments, or from any one of them, the nature and cause of electro-magnetic phenomena may be readily studied, and results predicated. It is evident, that, in all cases, the action takes place *tangentially*—a term that, perhaps, requires some explanation for those of our readers who are not familiar with mathematical expressions. In the annexed cut, *a* represents the centre of a circle, the circumference of which is shown by *b b*. Now suppose a line to be drawn as from *c* to *d*; this line is called a tangent, because it touches the circle at *c*—the term being derived from the Latin, *Tangere*, *Tangens*, to *touch*, or *touching*. Now, if we take any form of apparatus that has been described, we can explain the action that results from the influence of the magnet on an electrified wire, or *vice versâ*, in the following manner:—

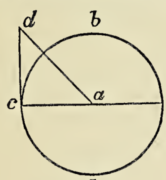


Fig. 207.

Suppose *a* to represent a molecule, or an exceedingly small portion of a magnetised body, and *c* a similar one of a body electrified by the voltaic current. The tendency of the action of these two forces on each other is, that *a* drives *c* towards *d* tangentially, and that *c* tends to drive *a* towards *b* on the left hand of the circle. Referring to the illustration of the vibrating wire, given at p. 386, *ante*, and Fig. 204, it is evident that there *c* is represented by one of the *fixed* poles of the magnet, whilst *a* is the end, *b*, of the wire standing in the mercury trough. Now the magnet is *immovable* from its weight; but the electrified wire is *movable*: hence it obeys the tangential projecting force, and leaps out of the mercurial trough. Precisely the same explanation is applicable to all the varied forms of apparatus that have been suggested, whether the magnet or the wire was put into motion.

At first sight, some difficulty may be experienced by those uninitiated to scientific reasoning, because of the different positions that parts of the apparatus take. Let us instance, by way of example, the revolution of the little voltaic cell (illustrated by Fig. 203, at p. 385) round the pole of the magnet. In that experiment the magnet takes the place of *a* in the preceding cut, whilst the zinc and copper cells are the *c*.

But another difficulty may arise in understanding how the tangential tendency can be converted into circular motion: and we will endeavour to explain this.

It is evident that if a line be drawn from *b* to *c d*, the two lines will form part of a rectangle or square inscribing the circle. But if a series of lines or tangents be drawn all round the circle, as represented by A, B, C, D, &c., in the following cut, they gradually approach nearer and nearer to the form of the circumference of a circle. Now, the figure here represented is only an octagon; that is, one having eight corners, the lines forming which are tangents to the circle. But supposing a polygon to surround the circle, then each of the lines will become of less length, and still more approach the form of the circumference of the circle. If, again, we suppose a polygon with little short of an infinity of sides, such a figure must differ little from a circle; indeed, inappreciably so in regard to all our powers of observation. Now, it is precisely in this way that the tangential form of repulsion (illustrated in the preceding cut, Fig. 208) becomes converted into one of rotation, or circular motion. As the repulsion is exercised, so the body, whether the electrified wire or the magnet revolving on a pivot, can only move circularly, although the tendency of its parts is to fly off tangentially.

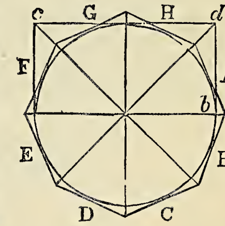


Fig. 208.

Some illustrations of the same result in nature may assist the imagination of our readers. It is well known, that if a tumbler, filled with water, and attached to a string, be *slowly* turned round in a circle, perpendicularly over the head of the experimenter, he will receive a cold bath for his pains; but if, by a little ingenuity, the tumbler be quickly turned round in a circle, every drop of water may be retained in the tumbler, although it has just as much tangential tendency as the wire or magnetised body now under consideration. Precisely the same thing is noticed in the stone and sling. So long as violent rotatory motion of the sling is maintained, the stone remains in it; but the moment the sling's motion is stopped, the stone flies off tangentially with great force.

But the closest analogy subsists between the action of gravitation, in respect to centrifugal force, and electro-magnetic rotation—not as regards cause, but only in phenomenon or action. For instance, the sun is the centre of our planetary system; the planets move round him nearly in circles; and the difference of the form of their orbits from a circle does not affect our purpose. The sun attracts all the bodies of our system towards its centre, but they do not fall into his mass. The reason of this is, that they have a projectile force, which

propels them tangentially *from* the sun into space. Thus, in the annexed diagram, let us suppose A to be the position of our earth at any moment. The projectile force of the earth would carry it—say in ten minutes—to M, along the line A D M; but, meanwhile, the attractive power of the sun—say acting from A to E—has drawn the earth from the straight line, A D M, downwards from D to B; and, consequently, the actual path of the earth, due to the conjoint action of its projectile force at the attraction of the sun, is not a straight line, but a curve, A B C.

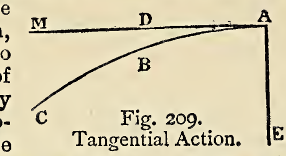


Fig. 209.
Tangential Action.

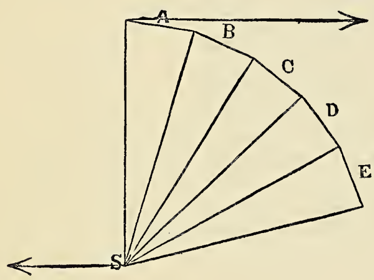


Fig. 210.

Now, this curve is made up of a series of polygons, as represented in the above diagram. A B C D E represent so many sides of the polygon described by the joint action of the projectile force of the earth, and its attraction by the sun at S. The sides in the cut are each of enormous comparative length; and it is evident that if their individual length were diminished, they would form a curve as near as possible circular in form. Now, suppose, for example, that S, in the preceding cut, represents the north pole of a fixed magnet, and A the point of an electrified wire. The electro-magnetic tendency would drive A to the right, and S to the left. But S is supposed to be fixed; and A, although movable, is suspended in such a manner that it cannot fly off tangentially: it is, therefore, compelled to form an infinite number of polygons, of an infinitely small size, and, consequently, equivalent, in practice and fact, to a circle.

Before we conclude this general view of motion obtained by the action of magnetised and electrified bodies on each other, we may notice an ingenious contrivance, invented by Mr. Barlow, for showing the rotation of a conducting body round its own axis; and, in some respects, resembling the experiment illustrated by Fig. 203, *ante*, at p. 385, in which the copper and zinc cylinders, forming a minute voltaic cell, revolved round the poles of a fixed magnet. The present case is also the reverse of that in which we spoke of the revolution of two magnets round a conducting wire. The results produced by the following experiment are of an interesting and important character, as still further illustrating the mutual yet opposite affections of an electrified wire and a magnetised body, subjects which have already been fully dilated on and illustrated in previous pages.

For the following description of the apparatus, as constructed formerly by Messrs. Watkins and Hill, of Charing Cross, we are indebted to Dr. Noad, the late eminent electrician, whom we have already frequently quoted in this work:—

"A horse-shoe magnet is supported vertically upon a stand, having holes formed in the centres of its ends. Two wooden circular troughs are secured by binding-screws upon the arms of the magnet, to contain mercury. Into the holes in the centres of the ends of the magnet two conical pointed wires are inserted, which are affixed in the middle of two hemispherical cups, united to cylinders, the rims of which are formed into points, which are dipped into the mercury contained in the circular troughs. Upon the top of each hemisphere is placed a small platina cup, to contain mercury. Other cups for holding mercury are supported on the external ends of bent wires, which pass through the sides of the circular troughs into the mercury contained therein. When a stream of voltaic electricity is passed through this apparatus, by means of connecting wires, placed in the mercury contained in the upper and lower cup, the cylinders commence revolving in opposite directions; that cylinder on the north pole, and down which the current is descending, moving, of course, from left to right. But if the two upper cups be united by a wire, and the lower cups connected with the positive and negative extremities of the voltaic battery, the same stream will traverse both sides of the apparatus, passing upward in one cylinder, and downward in the other; and the rotation will now, from the contrary influences of the poles, be in the same direction in both cylinders.

"Faraday showed that the results in the last experiment are the same when the magnet and conductor are united together; for, on fixing a thin piece of wood on the upper end of a magnet, loaded at its lower extremity with a platina weight, and floating in a vessel of quicksilver, and attaching to the wood an arch of strong wire, the whole apparatus commenced revolving on the transmission of the electric current through it; on the other hand, when a hollow cylinder of metal was balanced on a vertical axis of wood, and acted on by the poles of a magnet, placed *outside*, the rotatory force was very feeble. This affords us a means of explaining the circumstances of the rotation of a magnet about its own axis; for the explanation of that experiment will very much depend on the course which the current of electricity is supposed to take in its passage through the magnet. If it be supposed to pass through the interior, along the axis of the magnet, it would then occasion rotation, by its influence on the parts of the magnet that are situated nearer the surface; but if the course of the current be supposed to be along the surface, it will itself

be influenced by the polarity of those portions of the magnet which lie near the axis, and the rotatory tendency impressed upon it will produce the rotation of the magnet, which will, of course, be carried along with it. This, it will be seen, corresponds with the rotation of a conducting body round its own axis, a magnet being in the centre; and it has been just shown that the circumstance of the magnet and conductor being immovably joined makes no difference in the results.

"Another fact is made apparent by this last experiment; which is, that the electro-magnetic influence of the conductor takes place equally when the electrical current is diffused over a considerable surface as when it is circulated in a single wire. In the cylinder, every filament of which it is composed may be supposed to conduct its share of the current, and thus to contribute to the general effect."

We have already suggested some simple methods of changing the direction of the electric current in electro-magnetic experiments. At the present time there is an almost endless number of arrangements employed for the purpose of instantly changing the direction of the electric current in electro-magnetic experiments, for the electric telegraph and other purposes connected with electrical science and practice. It frequently happens that the change must be made instantaneously. In regard to the electric telegraph, what are called "switches" are largely employed, the name and character of the arrangement deriving its name from its large analogue employed on railways for trains, trucks, locomotives, carriages, etc., from one line to another.

Mr. Clarke invented an instrument which he called an *Electrepeter*, which was one of the earliest forms of these commutating instruments. It consisted of an arrangement by which a series of mercury cups connected with the battery and the apparatus allowed of instant change of communication. Its intention was to enable the experimenter to change the current with rapidity in regard to its direction, without being obliged to derange the apparatus by removing and rearranging the conducting wires. Ingenious as was the plan, it has entirely gone out of use, owing to more simple methods that have replaced it.

We have thus entered fully into what may be called the elementary portion of the science of Electro-Magnetism. To those who are unacquainted with the intricacies of telegraphy and other applications of electricity, many of our preceding remarks, descriptions, and illustrations will appear not pertinent to the general scope of electrical science. But to those who engage fully in the study and practice of applied electricity, it may appear that in many respects we have omitted the discussion of many important subjects. These will come under review in their proper place, where their value will be better understood than if we had here anticipated them.

Electro-magnets.—It is almost unnecessary for us here to enter into any extended description of the method of making soft iron magnetic, as that has already been in part done, and illustrated, whilst treating on the mode of making artificial magnets, at a previous page.

We have seen that, by the experiments recently suggested, conducting wires attain magnetic properties when a voltaic current passes through them; and it would naturally be supposed, that if they possessed such properties, they might induce them in soft iron temporarily, and in steel permanently; consequently we find, that when a current of voltaic electricity is caused to pass round iron, as shown in the following cut—in which *a a* is a helix of copper wire, and *b* a rod of iron, kept from touching the wire by wrapping it in a sheet of paper—the rod becomes at once magnetic. Fig. 192, p. 343, *ante*, still better illustrates the method.

Fig. 211.

That represents a considerable number of convolutions round the iron of covered copper wire; and the greater the number of such convolutions, the larger is the amount of magnetic force engendered.

But, when discussing the question of the distribution of magnetism, at p. 335, it was seen that the middle of a bar or horse-shoe magnet shows no signs of the force, and that it is only at the extremities where the magnetic force is evident and most powerful: from, or nearly from, the extremities the intensity or power diminishes, until the middle of the magnet be reached, where it is *nil*.

Bearing this in mind in the construction of electro-magnets, it is not necessary to encircle the whole bar or horse-shoe with the covered wire, but merely a portion of the poles; for there it is where all the power will reside, and, consequently, where alone it need be produced. The greater the number of convolutions employed, the more powerful will be the effect on the iron; but then, as the resistance to the passage of the current increases with the length of the wire, of course one cell will not be sufficient to overcome the resistance; and a number must be employed sufficient for that purpose. We have had two electro-magnets of the largest size at our disposal for experimental purposes, in both of which a great length—some two or three miles—of wire was employed; and required fifty cells of Grove's battery to fully excite them.

But it is not advisable, in making large magnets, to coil on the wire in one length. This is usually done by making successive coils piled one above the other, and their ends are respectively connected in series with a rod on each side, to which the ends of each coil are soldered. These two rods, consequently, act as two general conductors for all the coils, and distribute the electric current to each.

In making an electro-magnet, it is desirable that the iron should be as pure as possible; and that the copper wire should also possess

that property. The iron will retain a portion of the magnetism after the current has been cut off, instead of almost immediately losing it. We remark *almost*, because even the purest soft iron retains some portion of magnetism (called residual magnetism) after the current has ceased to pass round it. This is a subject to which we shall have again to revert when treating of the mutual effects of electricity and magnetism in respect to induction, the construction of electro-magnetic machines, &c.

In reference, however, to this, we may quote some observations made by Mr. Watkins, on the question of the retention of induced magnetism in soft iron after the cutting off of the electric current, as detailed in the *Philosophical Transactions of the Royal Society*, in 1833, and thus related by Brewster :—

"He found that when the armature, or keeper, is removed from the two poles of the magnet, it instantly [at least, apparently so] loses all its magnetism when the electric current is cut off; but that if the armature be kept on the poles, the soft magnet will retain its magnetism for a great length of time."

This phenomenon we did not observe to any extent when experimenting with the large electro-magnets, as already mentioned. At all events, the largest of the two permitted readily the removal of the keeper, although, whilst the current passed, it would sustain a weight of several tons, not holding even a fine needle after the current was cut off. But we continue the quotation—"Mr. Watkins made a horse-shoe bar with a piece of soft iron 18 inches in length and 1 inch in diameter, and he rendered it magnetic by winding round it, in a single helix, 20 feet of copper wire $\frac{1}{15}$th of an inch thick. The ends of the copper helix being connected with a single pair of voltaic plates, the horse-shoe, when rendered magnetic by the current, supported 125 pounds. The voltaic action continuing, the weight was reduced to 56 pounds, and the voltaic plates removed; the weight was also carefully removed, so as not to displace the armature, or keeper. The sustaining power of the horse-shoe was then tried every day; and at the end of ten days it sustained 56 pounds as firmly as it did at first. Another horse-shoe bar, charged with magnetism in November, was as powerful, and rather more so, in April than it was at first. After a lapse of fifteen weeks it frequently supported 30 pounds. This soft iron magnet was tried at the Duke of Sussex's house, on the 27th of April; *and, though nearly six months had elapsed since it received the magnetic virtue, it supported* 100 pounds; but the instant that the *keeper* was separated from its poles, almost all the magnetism disappeared. When the keeper was again applied, there was not enough of magnetism even to support the keeper.

"Mr. Watkins made some interesting experiments on the lifting powers of soft iron magnets, when plates of mica, of different thickness, were interposed between the poles and the keeper. The magnet was of the size and shape already stated; but Mr. Watkins has not mentioned the successive thicknesses of the mica plates, nor does he state that they were of equal thickness. Had he mentioned the tints which each of them polarised, it would have been easy to compute their exact thicknesses. The following were his results :—

Number of Plates of Mica interposed.	Number of Pounds supported besides the Keeper.
1	49
2	40
3	26
4	17
5	13
6	8
7	$4\frac{1}{2}$
8	$2\frac{1}{2}$
9	2
10	$1\frac{1}{2}$
11	1
12	$0\frac{3}{4}$
13	$0\frac{1}{2}$
14	The keeper only
15	0"

As we shall subsequently notice, this rapid decrement of force in electro-magnets, as the attracted body is removed from them, although so common when in contact, has been, together with the phenomena of residual magnetism, the great hindrance to the application of electro-magnetism as a motive power. A stranger, for the first time, seeing the enormous attractive power of an electro-magnet, is naturally led to imagine that the mechanical engineer has a most powerful source of force at his disposal; but, unfortunately, up to the present day, no successful application of electro-magnetism of that nature has been made. We shall see that by means of magneto-electric induction, all these difficulties have been overcome, and electricity, as a motive power, has become a great success.

Of course, a certain ratio as to the amount of attractive force produced in an electro-magnet must exist in respect to the size of the magnet itself, and that of the battery used. Thus a small magnet, with a single cell of a battery, will have its power much increased by doubling the size of the plates of the battery. A large magnet requires a large-sized cell to develop its full powers; and, as already shown, a number of them, provided its wire coils be long, because of the resistance that has to be overcome in the wire. Again, the number of coils employed, as previously shown, greatly affects the result. If they are all in one, the resistance would greatly diminish the effect. The following result, described by the celebrated electrician, Dr. Henry, of the United States, bears on the practical view of the question. Having fitted up a machine by which the amount of attractive power could be measured, he made a horse-shoe electro-magnet in the following manner :—

"A bar of soft iron, two inches square, and twenty inches long, was bent into the form of a horse-shoe, nine inches and a-half high; the sharp edges of the bar were first a little rounded with a hammer. The horse-shoe weighed twenty-

one pounds. A piece of iron from the same bar, weighing seven pounds, was filed perfectly flat on one surface, for an armature or lifter; the extremities of the legs of the horse-shoe magnet were also truly ground to the surface of the armature. Around this horse-shoe, 540 feet of copper bell-wire were wound, in nine coils of sixty feet each. These coils were not continued around the whole length of the bar; but each strand of wire, according to the principle before mentioned, occupied about two inches, and was coiled several times backward and forward over itself; the several ends of the wires were left projecting, and all numbered, so that the first and the last end of each strand might be readily distinguished. In this manner was formed an experimental magnet, on a large scale, with which several combinations of wire could be made by merely uniting the different projecting ends. Thus, if the second end of the first wire be soldered to the first end of the second wire, and so on through all the series, the whole will form a continued coil of one long wire. By soldering different ends, the whole may be formed into a double coil of half the length, or into a triple coil of one-third the length.

"In making experiments with this magnet, a small single battery was used, consisting of two concentric copper cylinders, with zinc between them; the whole of the zinc surface in action, including both sides of the zinc, was two-fifths of a square foot, and the quantity of dilute acid only half a pint. The following were the results:—

Number of Wires soldered to the Battery in succession.		Weight lifted in Pounds Avoirdupois.
1.	Each soldered to the battery in succession	7
2.	One on each side of the arch . .	145
2.	One from each end of legs . . .	200
3.	One from each end of legs, and the other from middle of arch .	300
4.	Two from each end	507
6.	Wires attached	570
9.	All the wires attached	650"

With the same magnet, and all the wires soldered to the battery in succession, the battery having a plate of zinc, twelve inches long, and surrounded with copper, so as that the latter faced both sides of the zinc, 750 pounds were held.

Of course, these experiments were made with the old form of battery, of the construction recommended by Wollaston. The modern Smee, or nitric acid batteries, produce infinitely greater effects; but the preceding facts are interesting, and to be relied on, as few persons have studied the production of electro-magnets more than did Dr. Henry.

We have already cautioned our readers against allowing their watches to get into contact with, or even nearly approach, an electro-magnet. Another matter that should be provided against, when large electro-magnets are experimented with, is, that the keeper do not fall so as to injure any person so soon as the current is cut off. Through neglect of this precaution, we, on one occasion, saw a man's leg broken. The magnet was suspended from a tripod stand, with its poles downwards; and as he incautiously stepped forward to take off the keeper, it fell on his leg. The best plan is, to have a rope tied round the keeper, hanging loosely from some object or the bent portion of the magnet overhead, when, if the keeper accidentally fall, no harm can ensue, as it will be arrested in its progress.

A very interesting apparatus can be fitted up by which an electro-magnet may be made to rapidly rotate between the arms of a fixed horse-shoe and permanent one. It is represented in the following cut. N S are the two poles of a permanent horse-shoe magnet: *a* is a brass rod,

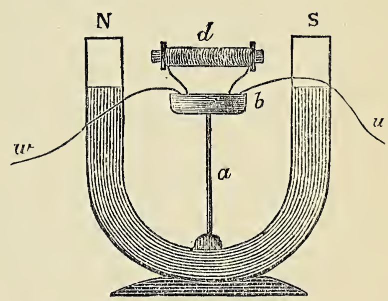


Fig. 212.—Rotating Electro-magnet.

which supports a wooden cup, *b*, intended to hold mercury. This cup is divided into two portions by a wooden partition, so that there are thus produced two cisterns of mercury, each of which is connected with the battery wires, *w w*. On the top of the brass rod, *a*, is a bar electro-magnet, *d*, the two ends of the wires of which dip into the two troughs of mercury in *b*. So long as the electro-magnet is unexcited it is only slightly attracted by the poles of the permanent magnet; but the moment a current of electricity is passed by the wires to the two mercury troughs, *d* becomes converted into a magnet: consequently, magnetic attraction is powerfully produced, drawing the magnet into the position of a straight line between N and S. But, whilst this is done, the wires of the electro-magnet have changed the poles of that magnet by entering cups conveying opposite electricity to that which previously excited each. Repulsion, therefore, ensues; and so a rotation will result at a very rapid rate, and continue so long as the action of the battery is permitted. 300 or 400 revolutions per minute may easily be kept up.

If the course of the current be reversed, the electro-magnet soon comes to rest, and instantly commences to rotate in an opposite direction. At the same time a bright spark is afforded, in either case, at the moment contact is broken, by the wires leaving the mercury cups.

This arrangement was, at one time, a favourite mode of making and breaking contact for medical

coils, or induction coils, which we shall hereafter extendedly notice; but it has the objection of scattering the mercury about in all directions, and, consequently, of stopping in case either of the troughs are emptied. The ends of the wires also burn, and, by constant re-amalgamation, get so brittle as soon to break off.

It will be observed, that the lifting power of an electro-magnet is much greater than that of a permanent artificial magnet. These, when fully saturated, will not lift many times their weight; but an electro-magnet may be made so powerful, that scarcely any force applied by the suspension of weight from the keeper will separate the latter from the poles of the magnet. Our ignorance of the difference between the condition of magnetism in a permanent and in an electro-magnet, prevents us being able to give any satisfactory reason of this difference.

Another singular fact also arises in connection with this department of our subject. In the preceding article on *Magnetism*, we have shown how readily, and in a variety of ways, steel may be saturated with magnetism. If, however, a steel rod be enclosed in a helix of covered wire, in the manner already frequently described, it will become permanently magnetic; but the amount of magnetism it will attain will be far less than that which can be communicated to it by another magnet. We have, for example, sent a current of fifty cells of Grove's platina battery, each battery having an active surface of twenty square inches, round a coil of No. 16 covered copper wire, the coil being twelve inches long, and containing about 300 feet of wire. A soft iron bar, placed in the centre of this, was rendered sufficiently magnetic to hold two or three pounds of iron nails at its extremities so long as the current passed; but when a piece of steel was so magnetised by the same current, coil, &c., its communicated magnetism was so much less that it would hardly hold any of the nails. Hence, in practice, the electro-magnetic method is not adopted for magnetising steel.

Not only have the extremities of an iron bar magnetic power of attraction, but the interior of the coil itself, at each end, exercises that force to a great extent. This, of course, might be expected to exist; but the repetition of the experiment is interesting.

For this purpose a hollow core of wood or gutta-percha, may have wound on it about fifty feet of covered copper wire, No. 16 gauge, the greater portion being spread over the two ends, for reasons already explained at p. 389, *ante*. If this be now excited by a powerful battery, and a rod of soft iron be so held as just to enter the end of the coil, the attractive force excited on the iron will be so great as to draw it into the coil. If it be attempted to remove the iron, it will be found that considerable force will be required for that purpose.

If a bundle of iron wires be inserted in such a coil, or even a rod of iron, and also when an electro-magnet is excited, a sudden sound is produced, that has been variously accounted for, and of which we shall have again to speak. It has been supposed that the mass of the iron undergoes a sudden change in its constitution, and so the sound is produced.

Of course, the centre of such a coil—at least, the centre of its extremities—must be the centre of the force, in section, exerted; and, theoretically, a light needle ought to be suspended horizontally in the air, like Mahomet's coffin; but, practically, this can hardly be accomplished, because, however light the needle, still, as all the forces acting on it are equal to each other in the coil, its weight, or tendency to obey the laws of gravitation, causes it to fall. If, however, it were possible to find a body that was susceptible of magnetic influence, and yet destitute of weight, it would be thus suspended in the centre of the coil; that is, in its axis, because this would be the resultant of all the acting forces.

Another phenomenon developed in using such a coil with a powerful battery, is the production of great heat. Using a battery of twenty or thirty cells, of Grove's construction, and connecting the two ends of the coil with the battery, it will be noticed that the centre of the coil, after a few seconds, becomes sensibly warm. After a little longer action, the heat will so increase as to cause the coil to become too hot to be held in the hand; and at last, if, as is often done, the exterior of the coil has been covered with a solution of shell-lac, or sealing-wax in spirits of wine or naphtha, this varnish will melt and smoke.

Although we are here anticipating, in fact, a future subject, we consider it advisable to do so in mentioning the following matters of precaution that must be adhered to in certain cases. If, in using an induction coil, the layers of wire in which are separated by thin sheets of gutta-percha, too powerful a battery be employed, the amount of heat thus produced may melt or soften the gutta-percha so much as to lessen insulation, and so greatly injure, if not destroy, its properties or powers. Three or four of such coils have, within our knowledge, been thus injured; and hence it behoves us to be cautious with such instruments, because they cannot be repaired without taking them entirely to pieces—a circumstance which causes an expense of reconstruction that will equal their first cost.

Many of our readers may be possessed of comparatively limited means, and the following remarks may assist them materially. When we first commenced the study of science, the cost of apparatus was enormous, because, so few persons being purchasers, the dealers had to make large profits from slow and limited returns. With only a lad's weekly pocket-money, however, we managed to repeat all the most essential experiments that have been detailed, by very simple arrangements.

In the first place, a battery that will serve all purposes may be constructed by bending a piece of sheet copper, six inches high and ten inches wide, into a cylinder six inches high. This is then to be put into a stone or glass vessel of the same height. A strip of zinc, an inch and a-half wide and seven inches high, is then to be amalgamated by rubbing it with a little mercury

and dilute sulphuric acid. To the copper and zinc plate, each, a wire two feet long should be soldered, to serve as conducting wires. The zinc should be suspended in the centre of the vessel, and kept from touching the copper by a small piece of cork or wood fixed between them, and supporting the zinc in an upright position. This simple battery is to be charged with a mixture of one part of sulphuric acid and eight of water, by measure. It will then afford abundant electricity for all purposes required by the economical student. Indeed, it was only by such a simple arrangement, or others just like it, that all the precedingly-related facts were discovered by Faraday, Ampère, Henry, and other philosophers, from the year 1820 to 1837, when improved forms of the voltaic battery were first introduced.

So much for the battery. Early in 1838, or 1839, we found that covered iron wire might be substituted for covered copper wire. We had a rod of iron, one inch and a-half thick and twenty inches long, bent into the form of a horse-shoe, with its poles about four inches apart. This was covered with No. 16 iron wire, coated with cotton, just such as is used by milliners in constructing bonnet-shapes. The cost of this is very much less than that of copper wire; but for all purposes of electro-magnetic experiments yet related it may be substituted for copper. The magnet, made as above, was very powerful; and when covered with another coil of wire, also of iron, and coated with cotton, but the wire being about 22 gauge, it afforded an excellent arrangement for the purpose of giving shocks; and, indeed, those so obtained were exceedingly severe. The whole affair need not cost two shillings; and, by making a contact-breaker, such as we have described at p. 391, *ante*, as good a coil machine may be constructed as some of those that we shall afterwards describe.

In respect to magnets, and all other necessary arrangements, enough has been said and illustrated in the preceding pages to enable any intelligent person to construct their own apparatus. None are so fitted to pursue science as those who are capable of making their own instruments. It not only renders them independent, but also tends to the discovery of improvements that may turn out of great advantage. It must be remembered that the apparatus before described was not that by which the discovery was made in any case; on the contrary, the apparatus was the consequence of the discovery. The philosopher, in his laboratory, employs rough instruments, put together, most probably, by himself, as we know was frequently the case with Faraday. When he had constructed something that suited his purpose, it found its way from the laboratory to the lecture-table; thence to the philosophical instrument-makers; and, at last, in a polished, varnished, and elegant form, it got into the possession of the purchaser. Some years ago we were invited by a nobleman (who shall be nameless because living) to inspect his laboratory. It had been fitted up, "regardless of expense," under the direction of one of our most able (then living) scientific men. But what with fear of spoiling it, and ignorance of its use, the apparatus might just as well have been so many stones. The whole place was one of neatness and order, but also of silence and scientific death.

So far we have examined some of the most elementary principles of the science of electro-magnetism. We have seen how an electrified needle acts on a magnetised one, and how the latter acts on electrified bodies. We next turned to consider a variety of electro-magnetic phenomena arising from such mutual relations or actions, and the production of rotation in bodies subject simultaneously to the forces of electricity and magnetism. What has been already stated may be considered as the base, or foundation principles, of the science; and the student should perfectly master each detail before proceeding to deeper investigations: for he who leaves a lot of little facts unlearned as he proceeds, is like a general who leaves behind him a number of small hostile towns in his rear, which, on his return, will turn an apparent victory into an inglorious defeat.

ELECTRO-MAGNETIC INDUCTION.

One of the most interesting results that were discovered by Faraday, was that which he termed *volta-electric induction*, but which has since been variously called, owing to the great expansion of the phenomena since its first discovery.

In a paper, read November 21st, 1831, and forming a portion of the first series of Faraday's *Experimental Researches in Electricity*, he remarks—"The power which electricity of tension possesses of causing an opposite electrical state in its vicinity, has been expressed by the general term *induction*, which, as it has been received into scientific language, may also, with propriety, be used in the same general sense to express the power which electrical currents may possess of inducing any particular state upon matter in their immediate neighbourhood, otherwise indifferent. It is with this meaning that I propose using it in the present paper."

He then refers to a variety of results that had been previously attained by Ampère, Arago, and others that have been previously described. At that time it was not possible, with the knowledge possessed, to account correctly for all the phenomena that had been observed; and, therefore, Faraday remarks—

"These considerations, with their consequences—the hope of obtaining electricity from ordinary magnetism—have stimulated me, at various times, to investigate, experimentally, the inductive effects of electric currents. I lately arrived at positive results; and not only had my hopes fulfilled, but obtained a key which appeared to me to open out a full explanation of Arago's magnetic phenomena, and also to discover a new state, which may probably have great influence in some of the most important effects of electric currents."

Of course, Faraday's early results were as nothing, in the amount of phenomena exhibited, compared to those we now obtain by similar, but more complete, methods. For example, he obtained a feeble spark, as we shall subsequently show, by his early apparatus; whilst, at the present day, by means of the *Induction coil*, constructed on the principles and laws discovered and laid down by Faraday, the spark has been obtained upwards of a foot in length. Nevertheless, the discovery has had such important results in experimental science, and its applications, that we shall not hesitate to describe how Faraday was led, step by step, to his success, and gained a still higher reputation amongst philosophers. He describes these steps as follows:—

"About twenty-six feet of copper wire, one-twentieth of an inch in diameter, were wound round a cylinder of wood, as a helix, the different spires of which were prevented from touching by a thin interposed twine. This helix was covered with calico, and then a second wire, applied in the same manner [that is, the second coil was wound over and on the top of the first]. In this way twelve helices were superposed, each containing an average length of wire of twenty-seven feet, and all [wound] in the same direction. The first, third, fifth, seventh and ninth, and eleventh of these helices were connected at their extremities, end to end, so as to form one helix; the others were connected in a similar manner; and thus two principal helices were produced, closely interposed, having the same direction, not touching anywhere, and each containing 155 feet, in length, of wire.

"One of these helices was connected with a galvanometer; the other with a voltaic battery of ten pairs of plates, four inches square, with double coppers, and well charged; yet not the slightest sensible deflection of the galvanometer needle could be observed."

A similar compound helix, with others, were constructed by Faraday; but, in all cases, he failed, under such circumstances, in deflecting the galvanometer by the coil attached to it whilst a current was passing or continuous in the other coil.

He, however, varied the experiments, and eventually hit on the discovery.

"Two hundred and three feet of copper wire, in one length, were coiled round a large block of wood; another 203 feet of similar wire were interposed, as a spiral, between the turns of the first coil, and metallic contact everywhere prevented by twine. One of these helices was connected with a galvanometer, and the other with a battery of 100 pairs of plates, four inches square, with double coppers, and well charged. *When the contact was made, there was a sudden, and very slight, effect on the galvanometer, and there was also a similar slight effect when the contact with the battery was broken.* But whilst the voltaic current was continuing to pass through the one helix, no galvanometrical appearances, nor any effect like induction upon the other helix could be perceived, although the active power of the battery was proved to be great by its heating the whole of its own helix, and by the brilliancy of the discharge when made through charcoal," or between charcoal points.

The slight deflection of the needle noticed by Faraday, caused by making contact, was always in one direction; whilst by breaking contact it was in the opposite. He consequently, on these experiments, remarks—

"The results which I had, by this time, attained with magnets, led me to believe that the battery current through one wire did, in reality, induce a similar current through the other wire; but that it continued for an instant only, and partook more of the nature of the electric wave passed through from the shock of a Leyden jar, than of the current from a voltaic battery; and, therefore, might magnetise a steel needle, although it scarcely affected the galvanometer."

Breaking off the account of the early researches of Faraday for a moment, we cannot help remarking on the great sagacity he evinced in the last-mentioned suggestion. As we shall eventually see, that suggestion has been amply verified in fact; for, as the current in the first coil partakes of, and, in fact, is chiefly the voltaic current—that induced in the second, or *secondary* coil, as it is now termed, partakes in all respects of the characters of electricity generated by friction; for, by means of it, all such phenomena may be reproduced as exactly as by the ordinary electrical machine. But continuing the quotation, he remarks—

"This expectation was confirmed; for, on substituting a small hollow helix, formed round a glass tube, for the galvanometer, introducing a steel needle, making contact as before between the battery and the inducing wire, and then removing the needle before the battery contact was broken, it was found magnetised." He also found that a needle, similarly treated, but only at the breaking of contact between the battery and first coil, produced the same effects; but the poles of the needle were reversed in character at the respective ends.

It is unnecessary for us to enter into a description of all the experiments tried by Faraday. He concludes thus:—"It is evident that currents of voltaic electricity present phenomena of induction somewhat analogous to those produced by electricity of tension [frictional electricity], although * * * many differences exist between them. * * * For the purpose of avoiding periphrasis, I propose to call this action of the current from a voltaic battery, *volta-electric induction.*"

We have forborne from entering further into the details of Faraday's early researches, because, as he states in his *Ninth Series*, in 1834–'35, "further investigations led me to perceive the inaccuracy of my first notions." He proceeds, then, to describe a great variety of ingenious experiments, by which he sought to investigate the *influence, by induction, of an electric current on itself, and of the inductive action of electric currents generally.* He describes a variety of helices he employed, and other apparatus; and we shall presently suggest a very simple method

of repeating his experiments, by which our readers may verify, observe, and study the results obtained. Gradually, he arrived at obtaining increased effects and new phenomena; obtained bright sparks, shocks, &c., from the *secondary coil;* that is, the one not connected with that which conveys the voltaic battery, and now called the *primary coil.* He also found, that on introducing a bar of soft iron into the centre of the helix, the iron became an electro-magnet (see *ante*, p. 389), and the power of the helix was instantly and greatly raised.

On changing a helix into a straight, long line of wire, the latter gave a much feebler spark than the helix; the strength of the spark being restored on the long straight wire being converted into the helix form.

"As the superiority of a helix over a wire is important to the philosophy of effect, I took particular pains to ascertain the fact with certainty. A wire of copper, sixty-seven feet long, was bent in the middle, so as to form a double termination, which could be communicated with the electromotor [battery or cell]; one of the halves of the wire was made into a helix, and the other remained in its extended condition. When these were used, alternately, as the connecting wire, the helix half gave by much the strongest spark. It even gave a stronger spark than when it and the extended wire were used conjointly as a double conductor."

He also showed how the length of the wire affected the spark; but this has already been illustrated by reference to Dr. Noad's experiments on the spark obtained from flat helices, at p. 382, *ante*, when we were speaking of the effect of resistance to currents in using electro-magnets.

We may here sum up these early discoveries in respect to the production of secondary currents by primary ones (the former being superimposed on the latter), by stating that Faraday first showed the influence that a wire carrying a voltaic current has of inducing a current in one parallel to that wire; that the helix form was most suitable to produce the effect of the spark, shock, &c.; that the inductive result in the secondary coil depends on its length; and that the currents so generated are only palpably evidenced in the secondary coil at the moment of making and breaking contact.

We shall here suggest a very simple apparatus, which may be readily constructed, for the purpose of examining most of the phenomena that have been described.

Take a wooden or gutta-percha tube, as thin as possible in substance, and coil round it regularly and evenly about 100 feet of No. 16 covered copper wire. The more regular the coiling is effected, and the closer each spiral or convolution is to the next adjacent to it, the better will be the instrument. Let the two extreme wires of the first or primary coil extend outwards two feet at each end, to serve as conductors.

Over this primary coil, wind, regularly and evenly, as just directed, 300 feet of No. 22 covered copper wire, so as to completely cover the primary coil from end to end; and leave ont at each extremity two feet of this wire, to serve as conductors. For our present purpose, a piece of brass tube, an inch in diameter and three inches long, may be soldered one to each extremity of this secondary coil.

Having charged a single cell of Smee's, or any other modern form of voltaic battery, connect one end of the primary coil with one of the plates. Let an assistant hold the other wire, whilst the experimenter, having first moistened the hands with salt and water, grasps the handles of the secondary coil. Now let the assistant bring the unattached end of the primary coil into contact with the other plate of the battery cell, and then instantly remove it. The experimenter will at once feel a shock. If the assistant connect the wire of the primary coil with a clean steel file, whilst he runs over the surface of the latter a wire proceeding from the plate of the battery, the making and breaking of contact will be so quickly effected as to produce a rapid succession of currents: with each of these a shock will be experienced.

Next introduce a bar of soft iron, or, still better, a bundle of soft iron wires, into the centre of the helix, and proceed as above; the violence of the shock will be so increased as to be barely supportable, showing how greatly the inductive effect of the current is increased by the induced magnetism. Our readers will understand why magnetism is thus induced in the iron, or introduced into the helix, by reference to p. 389, *ante*.

By these simple and easily-contrived arrangements, the student may learn much in respect to the phenomena of induced currents. That produced in the secondary coil results from the inductive action of the first, or primary coil. But this, also, has one induced in itself; hence it will be noticed, that a much brighter spark is produced when the current has passed through the primary coil, and at its extremity, than can be obtained directly from the battery. For example, if the plates of the battery have each a wire attached to them, and the ends be rubbed together, but a very faint spark will be perceived; but if one wire be attached to the primary coil whilst the other wire is rubbed against the other extreme wire of the coil, a bright spark is produced. The longer the wire the brighter the spark, "until, from extreme length," as Faraday observes, "the resistance offered by the metal as a conductor begins to interfere with the principal result."

To obtain the spark from the secondary current, let an assistant make and break contact with the primary coil by means of a file, as before directed; but instead of the experimenter holding the brass handles with moistened hands, let the handles be covered, except at the ends, with dry paper, so as to prevent any shock passing into the body of the experimenter. If, then, the ends of these handles be rubbed against each other, minute sparks may be obtained from the secondary coil, as battery contact with the primary is made and broken.

So far for the elementary principles of induced currents, and rudimentary illustrations of the

phenomena and their laws. Before proceeding further in the exposition of electro-magnetic induction, it will be desirable that we should, for the present, give some account of the fact first discovered by Faraday—that, by magnetic induction, we can produce electrical phenomena. We have already seen that electrical currents produce magnetism, and hence the result just alluded to is the converse of volta-electric induction. The facts embraced in the subject are aggregated under the term—

MAGNETO-ELECTRIC INDUCTION.

If a few feet of covered copper wire—say of No. 16 gauge—be wound round a core of wood or gutta-percha, or pasteboard, in the manner already explained at p. 392, *ante*, and the two terminal wires be connected with a galvanometer, of course no effect can be expected, because no force is set in motion; but if the pole of a bar magnet be introduced for a short distance into one end of the coil, the needle of the galvanometer will be instantly deflected. But, after this first deflection, if the magnet be still kept in the coil, the needle will return to its original place of zero on the scale of the galvanometer card, provided it had occupied that position on commencing the experiment. If now the magnet be half drawn from the coil, at that moment the needle will be again deflected, *but in an opposite direction* to what previously occurred. If, again, the pole of the magnet be reversed and re-introduced, the two deflections will differ; that is, if, in the preceding experiment, the deflection was to the right, then, in the second experiment, when the poles are changed, as introduced into the coil, the deflection will be to the left, and *vice versâ*.

By this remarkably ingenious and simple experiment, Faraday first showed the production of an electric current by magnetic action. Another method, in which an electro-magnet was employed, is thus described:—

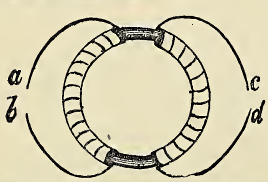


Fig. 213.—Magneto-electric Induction.

"A ring of soft iron was taken and enveloped in two spiral copper wires, as represented in the above diagram, each wire being insulated. Of these spirals, the ends of one, *a b*, were arranged for attachment with a voltaic combination; whilst the ends of the other spiral, *c d*, were placed conveniently for attachment with a galvanometer. A voltaic current being now caused to circulate through the spiral, *a b*, the galvanometer-needle was immediately deflected. When both helices were in the same side of the ring, the amount of deflection was still greater."

Now, in these experiments we see at once the phenomenon that has been called *magneto-electric induction*, in contradistinction to *voltaic-electric induction*, already very fully described at p. 393, *ante*, *et seq*. In the present case, as in that, the current is only produced *at the moment of making and breaking contact*. We must, however, notice that the magnetic induction is not instantaneous, as is the electric. We have already shown that electro-magnets neither gain nor lose their magnetism instantaneously, but that they require time for this purpose. This point has been entered into at considerable length at p. 390, *ante*, to which we accordingly refer the reader.

The phenomena thus developed by Faraday soon attracted the general attention of philosophers, and numerous machines were invented

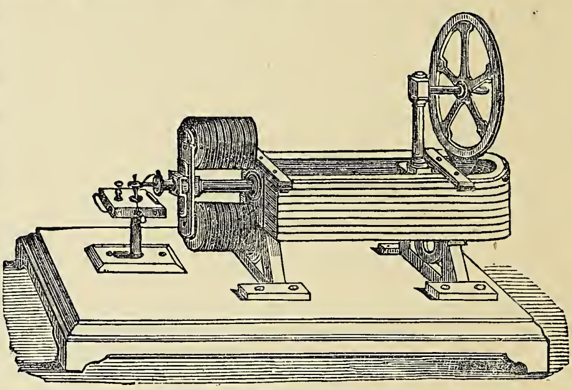


Fig. 214.—Saxton's Machine.

for the purpose of giving increased effects. One of the earliest was that of Mr. Clarke. In this an armature of iron, with coils of copper wire, was made to rotate rapidly before the poles of a battery of horse-shoe permanent magnets. By such an arrangement, all the heating effects shown by the voltaic current, its chemical, physiological, and other effects, were exhibited. Some years ago we possessed one of the original machines of this class. It ignited about two inches of platina wire, decomposed water, and exhibited various other phenomena.

Saxton's machine was much preferable. It is represented in the above cut. On the right-hand side are the horse-shoe magnets, arranged horizontally; and in front of them the armature, which is caused to revolve rapidly by means of a multiplying wheel fixed within the magnets. At the left is the contact-breaker, by whose action the succession of currents is produced.

Of late years great improvements in these machines have been made. Small ones are now commonly to be seen in the shops of the instrument-makers, and are sold for medical purposes. An inspection of one of these will teach at once the mode of construction, &c., better than any written remarks; and a shock from one will be a convincing proof of the production of an electrical current.

One of the best forms of such instruments is that constructed by Mr. Ladd, of Beak-street, London. In it the magnets are placed vertically. The kind to which we refer is composed of sixteen permanent magnets, and has sufficient power to render several inches of platina wire red-hot. It also affords a brilliant light between charcoal points. It is worked by hand. In the chapter devoted to the consideration of the Electric Light will be found a description of the machine of M. De Meritens, which was the only one in which permanent magnets were employed at the Electrical Exhibition at Paris in 1881, and thus formed a kind of union between the old and new dynamo-machines.

Other forms of the instrument have been employed for a variety of purposes. In Birmingham, etc., the magneto-electric machine is now solely used for electro-plating purposes,* in depositing silver, which it will do, if of proper size, to the extent of any quantity per hour.

One of the most interesting applications of these machines is that of producing the electric light, which was first successfully done, by means of magneto-electricity, by Mr. F. H. Holmes, through whose kindness we, in 1856, had the pleasure of witnessing his experiments at Trinity Wharf, Blackwall. The result of the experiments was exceedingly interesting. As most of our readers are aware, a voltaic battery cannot be kept in constant action for more than a limited period, when its powers become exhausted. At the early experiments above mentioned, Mr. Holmes succeeded in maintaining a continuous and brilliant electric light for two hours. Since then he has successfully employed the arrangement at the Foreland and Dungeness lighthouses; and many of our readers will remember, that, at the Exhibition in London, in 1862, a machine was exhibited by Mr. Holmes, that, in the production of light, even equalled, in its shadow, that produced by a partially obscured sun. The form of his machine very much resembled the common cotton-carding engine; and he employed peculiar apparatus, in the form of an electric lamp, to render the light steady. This we shall deal with subsequently; but the following extract from a paper read by him before the *Society of Arts*, in 1863, will explain the peculiarity of the construction of the machine he employed, and also other phenomena of magneto-electricity.

After describing the many difficulties incidental to lighthouse illumination, and showing that, above all things, a light of penetrative power is requisite for such purposes—and this quality the electric light has above all others—he observes—

"Let us now see whether electricity can produce a constant, steady, or uniform light. Frictional electricity will give a succession of flashes intensely vivid, and might be used for the purpose, but for the fact that the slightest moisture is sufficient to convey the whole charge to the earth. The various forms of galvanic battery are all capable of producing a steady and intense light; but still (besides the great expense) they are not applicable, because of the necessarily varying current, which becomes weaker and weaker as the solution arrives at saturation. The magneto-electric machine is, then, the source from which one would naturally expect a light which should be invariable in its nature, and capable of being continuous for any given time, as the current produced by this machine is constant as long as the helices revolve with the same speed; and the speed can be easily regulated to any required velocity.

"The electricity derived from a magneto machine is induced in coils of wire by changing the magnetic polarity of pieces of soft iron inclosed within the coils or helices; and the quantity or intensity of the induced current depends, first, on the amount of magnetism induced in the soft iron; secondly, on the facility with which the poles of the magnetised soft iron can be reversed; thirdly, on the velocity with which the change of polarity takes place; fourthly, on the length and diameter of the wire forming the helices.

"The amount of magnetism induced in the soft iron depends on the size and force of the steel magnets employed, and on the weight and softness of the iron in the helices; but the weight, in practice, of the soft iron is limited by the weight of the steel magnets; for, if too heavy, the steel magnets will be slowly deprived of their magnetism. To facilitate the change of the poles, the soft iron cores of the helices are not solid pieces of iron, but are tubes, single, double, or treble; as it is found by experiment, that the same weight of iron, when divided in this manner, loses or takes magnetism in much less time than when in a solid form.

"There is a limit to the velocity to be employed when the maximum of electricity is required, for this reason:—It has been already remarked that the amount of electricity depends on the amount of magnetism taken up, and that the soft iron takes time to become saturated, as it may be termed, with magnetism; hence, if the velocity be too great with which the cores move from one pole of a magnet to another, there will not be sufficient time for the cores to become saturated. But as, again, the quantity of electricity increases as the velocity increases, it is necessary to ascertain this maximum point exactly; which is easily done, either by experiment or calculation, based on certain data. The length and diameter of the wire require to be different, according to the current required; for a short thick wire forming the helices represents a galvanic battery composed of a dozen, say, of very large pairs of plates; whilst a long thin wire would represent a battery composed of thousands of small plates. In other words, supposing the size of the helices to remain the same, if they are composed of thick short wires, quantity is obtained; but if composed of long thin wires, intensity is the result.

"From all this it results that there are certain laws known and established, by which a magneto-electric machine can be made to give a current of any given amount of electricity, with any given ratio between its quantity and intensity.

* See separate article on *Electro-Metallurgy*.

"Having seen on what the production of the current depends, the next point to observe is the peculiar nature of this induced current. It differs essentially from a galvanic current in this—that, while the helices are revolving, the direction of the current is reversed as the core of soft iron passes each consecutive pole of the steel magnets.

"It now remains to explain how the current, generated in the wires of the helices, is to be withdrawn from the machine. In the first place, all the helices are connected in two, four, or more series; and, in doing this, great care must be observed that the direction of the coil of every alternate helix is in an opposite direction; that is, if one is wound as a right-hand screw, the next should be as a left-hand screw; or, what amounts to the same thing, supposing all wound in the same direction, then the two inner ends of the wires must be joined of, say, Nos. 1 and 2, and the two outer ends of the wires of Nos. 2 and 3, and so on through the series; and, lastly, the terminals of the series might be soldered into two insulated discs, and then led from the machine by two pieces of metal kept in contact with the outer surfaces of these discs by a slight spring. Such an arrangement allows the alternating current to pass from the machine; and such a current will produce a light, but this light has certain disadvantages. It is never white, but always, more or less, blue or brownish; in fact, it is, like the electric light, obscured by placing it behind a flame from spirits of wine. It is also extremely injurious to the eyes, both from its colour and tremulousness. I therefore do not use this current; but, in its stead, I convert this constantly-inverting current into two, that flow from the machine in one direction only. This is accomplished thus:—One-half of the helices are arranged so as to arrive on the poles of the magnet at the instant that the other half are exactly midway between the poles. Thus there are two distinct currents; and what may be called the dead point—that is, the point when the current inverts in one series—occurs exactly at the time when the other current is at its maximum; so that if now the inverted currents can be again inverted in both of these distinct currents, and that the two, now flowing in one direction, can be united as one compound current, it is evident that the result will be a current nearly as uniform as that from a galvanic battery, with the advantage of equable continuity. This is done by the two commutators, which consist each of two insulated rings of metal, of such a form at the periphery, that two rollers, or rubbers, change sides from one disc to the other at the same instant that the current is reversed. Then, by combining the two commutators, a compound current is obtained, that will produce a constant white light, or perform any of the other functions of the galvanic current, and in a more perfect manner, as it is more uniform in its action.

"A steady and constant current, thus obtained from the magneto-electric machine, is only one part of the problem of producing a constant and steady light; and although the most important part, still it would be perfectly useless without an efficient lamp or regulator. In order to understand this, it is necessary to explain, that the carbon points used for producing the light, or for converting a portion of the electric current into light, are consumed; and that the rate of consumption is irregular, owing to the irregularities in the structure of the substance used, which is the kind of graphite deposited in the gas retorts, sawed up into pencils about a quarter of an inch square; but, as the consumption is irregular, no clockwork, with continuous motion, could be employed for the purpose of causing the carbons to approach as consumed; for it must be understood that the steadiness of the light, as well as its brilliancy, depend on the two carbon points being maintained constantly at a certain distance, corresponding to the strength of the electric current."

Few applications of the discovery of Faraday, so far as we are capable of judging, so much pleased him as the one above described. We have heard him, in public and private, speak in eloquent terms of the light thus produced flashing across the Channel from the English to the French coast, where, on clear nights, it is distinctly visible, as the means of saving the lives of our brave seamen. It is impossible, in fact, to over-estimate the benefit that has arisen, and may arise, from the more extended application of the discovery of Faraday; and well might that philosopher delight in such a result.

Although somewhat anticipating the questions that have to be discussed, we should be doing an injustice to a most successful application of magneto-electricity that was very recently made, and created much sensation in scientific circles, in regard to general results, but especially in the production of a most powerful and permanent electric light, if we did not quote the following from Mr. Noad's work on the *Induction coil:—*

"It has been discovered by Mr. Wilde* (1866), that an indefinitely small quantity of magnetism is capable of evolving an indefinitely large amount of dynamic electricity. When the wires forming the polar terminals of a magneto-electric machine [see that of Mr. Ladd, fully described at p. 397, *ante*], were connected for a short time with those of a very large electro-magnet, a bright spark could be obtained from the helices of the latter twenty-five seconds after all connection with the magneto-electric machine had been broken; hence it would appear that the electro-magnet possesses the power of accumulating and retaining a charge of electricity in a manner somewhat analogous to that of the Leyden jar. Mr. Wilde also noticed that the helices of the electro-magnet opposed a certain resistance to the magneto-electric current, and that it required, in some cases, nearly half

* The similarity of this gentleman's name, in sound, with that of the author of this work, requires that the latter should, in justice to the former, state that in name alone is there any relation.

a minute before the current attained a permanent degree of intensity. Four permanent magnets, which, collectively, could only sustain forty pounds, could be made to evolve an amount of electricity sufficient to excite an electro-magnet to such a degree as to enable it to sustain 1,080 pounds ; and, by suitable arrangements, the electro-magnet could be made to evolve a large amount of dynamic electricity. The magneto-electric current produced by a machine containing six permanent magnets, which weighed only one pound each, and, collectively, could only sustain sixty pounds, was made, by Mr. Wilde, instrumental in producing a prodigious amount of dynamic electricity. The direct current from the magneto machine was sent through the coils of the electro-magnet of another much larger electro-magnetic machine. The result was the production of magnetism in the latter far exceeding anything that has been hitherto produced, accompanied by the evolution of an amount of dynamic electricity so enormous as to melt pieces of cylindrical iron rod, fifteen inches in length, and one quarter of an inch in diameter, and to produce, in the electric lamp, a light which cast the shadows from the flames of the street-lamps a quarter of a mile distant upon the neighbouring walls, and their rays from the reflector having all the rich effulgence of sunshine. The light and heat are increased according to the amount of mechanical force employed."

Having witnessed the above results, we can unhesitatingly confirm their truthfulness; and only add that, although having possessed some of the most powerful voltaic arrangements of all kinds that have yet been constructed, the results Mr. Wilde has obtained cast all others into the shade, literally and figuratively.

A great point of interest in the preceding results is also found in the fact, that motion produces, in a single arrangement, all the forces—heat, light, electricity, and magnetism—simultaneously, and in a state of the highest intensity. Mr. Wilde's arrangement, in fact, apart from the wonderful effects obtained, may be taken as a physical illustration of the modern theories of the cause of the forces just named.

A very simple but ingenious experiment may also be tried to show the development of electricity. At p. 360, *ante*, we have stated, that an electro-magnet we formerly possessed, acted so powerfully on a rotating disc of copper as to stop that rotation when the electro-magnet was excited. Again, at p. 386, *ante*, we have shown that a copper disc may be made to rotate rapidly on its axis, if placed under the conjoint influence of electricity and magnetism. We now proceed to show that a rotating copper disc may, by the joint influence of magnetism, produce an electric current. In the following cut, *a* represents a thin copper disc, that can be quickly turned round by a handle, *b* ; a wire, *c*, is connected with the axis, *d*, whilst another wire, *e*, presses against the circumference of the copper disc, on each side of which are placed the opposite poles of a horse-shoe magnet, *m*. If the wires, *c*, *e*, be respectively connected with the terminals of a galvanometer, a current of electricity will be noticed. If the disc revolve from the right

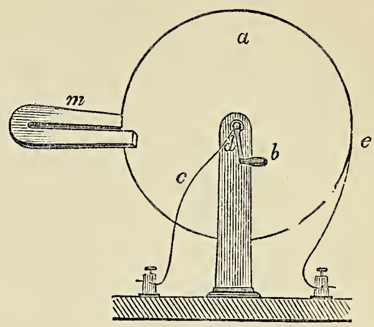


Fig. 215.

to left, according to the direction of the poles of the magnet, a current will be established from the axis of the wheel to its circumference, and it will deflect the galvanometer. An opposite revolution of the copper disc, or a reversal of the poles of the magnet, will reverse the direction of the current.

So far we have only described two forms of the magneto or dynamic machine as applied to the production of the electric light. The reader, on referring to page lxxx., *et seq.*, in the Introduction, Vol. I., will find a description and illustration of one in large use in 1881, and in the chapter on the "Electric Light," which follows, other modern forms will be described and illustrated.

Having thus given a general outline of the principles of magneto-electric induction, we shall now revert to the consideration of such results as have arisen from their application to the construction of what are called—

Inductoria, or Induction Coils.

At p. 395, *ante*, we have given a description of an elementary form of such coils. It was then stated, that if a primary coil be wound on a core of wood, or other substance, and a secondary coil of fine wire be wound on this, a bundle of iron wires or a rod of iron being introduced into the centre of the core, and contact with a single cell of a voltaic battery be constantly made and broken, a series of secondary currents would be produced in the second coil, whilst shocks, sparks, &c., might be obtained, proving the existence of that secondary current.

We must here point out that which has been previously hinted at—viz., that the current of the thick, or primary coil, corresponds, in its character, with that of the voltaic current; whilst the current generated in the secondary coil corresponds with the kind of electricity developed by the frictional electrical machine. In other words, the primary coil gives electricity of quantity, whilst the secondary coil gives electrical intensity. There is a limit to the amount of quantity or quantitative effects that can be developed by the primary coil, owing to the resistance of the wire to the passage of

the current; for, as Faraday showed, that resistance might overcome the primary result, or acting cause—namely, in the latter case, the exciting current of the voltaic battery.

Some very interesting results, obtained by Mr. Noad, have been related in part at p. 382, *ante*. As his experiments were amongst the first that we tried in relation to induction, &c., in a primary current; and, moreover, although unacknowledged in many respects in certain quarters, they deserve full consideration, we shall complete the extracts from his work, so as to place that gentleman's early investigations in a true light, consistent with their value; for, to a certain extent, they formed the basis of the modern induction coils, of which Mr. Noad has, since their introduction, given a very luminous account. Continuing from paragraph (6), as seen in p. 382, *ante*, he relates the following results :—

"7. The shock with this apparatus did not increase with the spark: when one of the brass conductors of Clarke's electro-magnetic machine was grasped by the hand, and kept permanently in 1, and the other held in the left hand, and dipped successively into each of the other cups, in which contact with the battery was rapidly broken by an assistant, the large calorimeter being employed, the following were the results :—

"8. The left-hand conductor being in cup 2, and contact with the battery broken in it, the shock was very slight; in 3 it was stronger, and went on increasing to 10, where it was strong enough to be felt at the elbows; now the spark and snap were most intense in 2, and least in 10; hence the shock appears to be inversely as the spark.

"9. The left-hand conductor was then dipped into the cup, *next* to that in which contact was broken, being out of the circuit of the current; as, for instance, in 3, while contact was broken in 2, the shock went on increasing, as before, to the end of the arrangement; it was then kept permanently in 6, while contact was broken in all the other cups; in 2, 3, 4, the shocks were distinctly felt, and went on increasing to 9.

"10. The current was then passed from 2 to 9, while the conductors were held in 1 and 10, then from 3 to 8, then from 4 to 7, then from 5 to 6; shocks were felt in all cases, strongest when the current was from 2 to 9, and weakest when from 5 to 6.

"11. The wires from the battery were then connected with 1 and 2, and the conductors held in 3 and 4, then in 1 and 3, while the conductors were in 4 and 5, 1 and 4, 5 and 6, &c.; but no shocks were felt even when the wires from the battery were in 1 and 8, and the conductors held in 9 and 10.

"12. Although, however, no shock could be obtained *directly* from this arrangement, yet the existence of a secondary current was easily proved by the galvanometer, when the positive wire from the battery was in 1, and contact broken by the negative wire in 2, one wire of the galvanometer being in 3, and the other in 10, the needle was strongly deflected in a direction indicating the passage of a current in the same direction as the inducing current; that is, from 3 to 10. When the needle had taken up its position, it was retained in it by a pin, contact was then broken in 2, and the needle was immediately deflected in a contrary direction, showing now the passage of a current from 10 to 3.

"13. By employing Callan's coil (an arrangement to be described presently), powerful shocks were obtained from the secondary current; the wires from the large calorimeter being in 1 and 2, and the terminal wires of the primary coil in 3 and 10, shocks felt at the elbows occurred every time contact was broken; and when this was done rapidly by a revolving wheel (Fig. 208 *ante*), or by Ritchie's rotating magnet (Fig. 212 *ante*), the succession of shocks was almost intolerable; and when one of the wires of the primary coil was dipped in the same cup in which contact with the battery was broken, the shocks were very violent, even with a half-pint battery. When a wheel was employed to break contact, the scintillations were very brilliant when it was connected with the first four cups of the coil. The well-known optical illusion, of a body in rapid motion appearing stationary, was beautifully shown when the room was darkened, and the large battery used. Without the intervention of Callan's coil, the shocks obtained by breaking contact, by means of the wheel in the arrangement (8), were not so strong as was expected; the most efficient method in this case was to draw the end of the connecting wire rapidly over the edges of the ribbon, from the centre to the circumference.

"14. I obtained secondary shocks from the coil *immediately*—that is, without the intervention of Callan's apparatus—by dipping the conductors grasped by the hand in No. 10, and the negative cup of the battery, while contact was broken in Nos. 2, 3, 4, 5, 6, 7, 8, 9; in the last three, shocks were as strong as could be given with any other arrangement of the apparatus; and when Callan's coil was interposed, very severe, even when contact was broken at 2, and a half-pint battery employed.

"15. The wire from the zinc end of the battery was then kept permanently in 10, and contact with the copper end broken in 9, 8, 7, 6, 5, 4, 3, 2, the left-hand conductor in 1, and the right in the positive cup. Shocks were felt in all: slight in 9 and 8, but strong in 4, 3, 2."

Mr. Noad adds, that—

"After these experiments were made, the ribbon was cut down the middle and soldered together, so as to form a length of about 460 feet, half an inch wide, which was insulated, and wound as before into a spiral: the maximum spark with this arrangement, a pint battery being used, was at about 150 feet; and with a very small voltaic pair, the largest and brightest spark was still at the extremity of the spiral: on the whole, the effect of dividing the copper ribbon was, to diminish the size of the spark, but greatly to increase the intensity of the shock, which, when obtained from the last cup,

and the negative end of the battery, was very severe. Water was readily decomposed by the secondary current developed by this arrangement."

The Callan's coil, before mentioned, was simply a coil of thick covered copper wire wound on a wooden core, to serve as a primary coil, and another coil of about 1,500 feet of thinner covered wire wound round a cylinder, the primary coil being introduced into the axis of the thinner or secondary one. In fact, its arrangement has already been described when we recommended a similar coil as an experimental apparatus (see p. 395, *ante*) for students commencing inquiries in electro-magnetism.

From all the preceding facts, experiments, &c., it is evident that the primary coil represents the element of quantity, and the induced current that of intensity, in a double or greater number of coil arrangements. But it does not necessarily follow that only one induced current can be produced by the induced action of a primary one. It was shown by Professor Henry, of the United States, that a succession of alternating currents could be produced by the inductive action of one primary. He employed a similar arrangement of copper ribbon already described as used by Mr. Noad in the precedingly-related experiments ; and he found that, if the primary be positive, the secondary positive in direction, then the third was negative; the fourth positive ; the fifth negative; and so on. As Mr. Noad justly remarks—"Induced currents of the different orders [just named] are also produced by frictional electricity. On discharging a large Leyden jar through a spiral of tinfoil pasted round a glass cylinder, a small spiral of foil being pasted inside the cylinder, the ends of which were connected with a magnetising spiral enclosing a steel needle, the latter was magnetised in such a manner as to indicate an induced current through the inner ribbon, in the same direction as that of the current of the jar; a spark was also produced when the ends of the spiral were separated by a small interval. Induced currents, of a third and fourth order, were obtained when a large Leyden jar was substituted for the battery, the coils being furnished with a doubly insulating coat of silk, and the conductors separated by a plate of glass. By using a powerful Leyden battery, Dr. Henry obtained evidence of the induction of a secondary current at the surprising distance of twelve feet." Faraday relates a similar result, in his *Researches*, in respect to static electric induction. And, according to Reiss, currents of odd orders, as 3, 5, &c., have the same direction as the original current ; and even orders, as 2, 4, &c., have among themselves one and the same direction.

Quitting the principles, for the moment, on which coil and induction machines are constructed, we may notice a few of the early forms antecedent to that of Rhümkorf, in which a large amount of intense electricity is afforded, and which, by its subsequent improvements, has put us into possession of an instrument by means of which all kinds of static and dynamic electric phenomena, and their effects, may be exhibited.

One of the earliest forms that we can remember as having come into general use, consisted of coils, secondary and primary, wound on a bobbin, with an internal bar of iron. The contact, in this arrangement, between the primary coil and the battery was broken by a toothed wheel and spring, the wheel being turned round by a multiplying wheel. The wheel was composed of a series of conductors and non-conductors, made by filing out portions of the wheel, and replacing them by pieces of ivory or wood. The current was conveyed by attaching one wire of the cell to one end of the primary coil, and the other in such a manner that it should traverse the primary coil and also the metallic portion of the wheel ; consequently, whenever the spring proceeding from one end came in contact with the wheel at the metallic part, contact was made ; but immediately, by the revolution of the wheel, the spring came in contact with the ivory or wood, and, consequently, contact was broken with the battery. The form of coil with the next to be described was chiefly used for the purpose of giving shocks, and of administering electricity in rheumatic, paralytic, and other nervous diseases ; in cases of asphyxia, from inhaling carbonic acid gas, drowning, etc. The power of the shock could be regulated by the removal from, or gradual introduction of, the iron rod into the hollow of the cylinder on which the coil is wound; by means of which the magnetic effects of induction are lessened or increased. Another plan, having the same result, is that of interposing a column of water between one of the wires of the secondary coil and the handle; for as the liquid conducts to a much less extent than the metal, the intensity of the shock received is readily proportioned, by the length of the liquid column, to the condition of the patient. For a long time this form of instrument was not the subject of improvement. In many instances it was used simply as an illustration of the production of a secondary current so far as its philosophy was concerned. The toothed wheel above referred to was often made of different metals so as to show their combustion.

Of course, it was not self-acting ; and, consequently, left much room for improvement. One of the first methods to render the coil self-acting—that is, in respect to the breaking of contact—was that of employing the rotating electro-magnet, described at p. 391, *ante*, and illustrated by Fig. 212. As there stated, this was long a favourite form of the machine for the purpose of giving shocks. But it had the inconvenience of getting out of action from two causes. If the magnet rotated rapidly the mercury was driven out of the cups ; and, again, the terminal wires of the rotating electro-magnet became oxidated, and, consequently, the contact between them and the mercury was imperfect, whence the self-acting character of the machine was impaired. One of the best and most useful forms that have been constructed (and these have, indeed, been numerous and various), is that

represented in the following cut. It consists of a cylinder of wood, or other material, on which

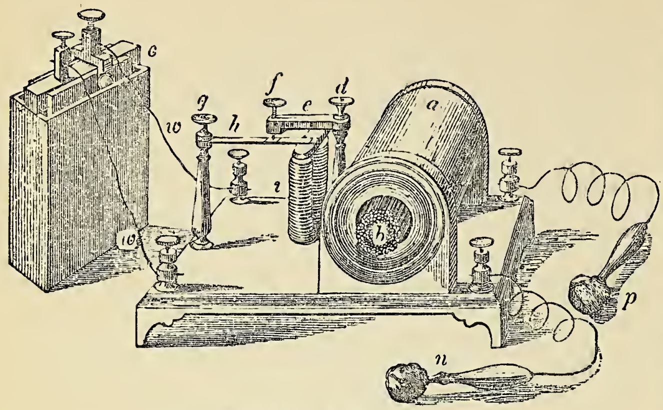


Fig. 216.—Coil-machine.

the primary and secondary coils are wound : *b* is a bundle of iron wires, placed in the centre of the coil; and *n* and *p* are the two terminals of the secondary coil. The primary generally contains about 100 feet of No. 16 gauge covered copper wire; and the secondary has often so much as 300 or 500 feet of No. 22 or 24 wire. One wire of the primary coil is attached to one of the binding-screws, in which a wire, *w*, from the battery, *c*, is fixed ; and the other wires, of both the battery and coil, are in connection with the contact-breaker, which next deserves our attention.

By means of this apparatus, the current proceeding from the battery is suddenly passed to, and cut off from, the primary coil. This is effected by means of a small electro-magnet, *i* : over this is placed, at a little distance, a soft iron keeper, which is connected, by means of a steel spring, *h*, with a brass pillar, *g*. A wire is fixed under the instrument—passing from one of the binding-screws, which holds one of the battery wires. The other end of the primary coil is attached to the pillar, *d* ; and from this stretches an arm, *e* ; at the end of which is a screw terminating in a metallic point, *f*. The electro-magnet, *i*, however, forms part of the circuit, by means of wires arranged beneath the foot of the instrument. Now, if a current of electricity be made to circulate through the coil by the means we have named, the electro-magnet immediately attracts the keeper placed over it, and, by drawing it down, removes the spring to which it is attached from being in contact with the metallic point terminating the screw, *f*. As the coil and battery are, electrically speaking, only brought into connection when the spring, *h*, and the point, *f*, are in contact—it follows, that the moment they part, the current is at once cut off from the coil. On this happening, the electro-magnet, *i*, loses its magnetism, and, therefore, ceases to attract the keeper over it. The spring, *h*, then acts, and again brings itself in contact with the end of the screw, *f*. The coil is thus again in connection with the battery, and the electro-magnet is magnetised. The previous conditions are repeated ; and thus the contact between the battery and the coil may be made and broken with great rapidity.

As we have already stated, a secondary current is induced in the fine coil each time when contact is made and broken between the primary coil and the battery ; and as this is easily done 500 times per minute, as many induced currents are simultaneously produced, and a torrent of electricity afforded. There is, however, a great difference between the character of the two currents. That of the primary, which is derived from the battery, has all the characteristics of the voltaic current ; whilst that afforded by the secondary coil presents effects precisely similar, in many respects, to the phenomena of frictional electricity ; and this identity is developed just in proportion to the length of the coil employed—all other circumstances remaining the same.

In our engraving, the terminals of the fine coil are attached to two handles ; and if these be grasped by the hands, previously moistened with salt and water, a most powerful shock may be obtained. If the secondary coil be very long, and the battery attached to the primary be in good action, the effects on the muscles of the arm are so powerful, as to make it impossible for the person receiving the shock to leave hold of the handles ; and the pain produced is most excruciating. In fact, considerable caution should be observed in this respect, especially with young persons and females, as serious consequences may result from inadvertence. It is better to place the end wires of the secondary coil in two basins of water, into which persons desirous of receiving a shock can immerse the hands ; and from which they, generally speaking, far more quickly withdraw them. Two or more persons can jointly receive the shock by joining hands together. The effect, however, rapidly diminishes as the number is increased ; and varies very much according to the susceptibility of each individual.

In some arrangements, means are provided by which the strength of the shock may be regulated according to the necessities or endurance of the patient. They are of varied character, but need not be here described.

But it is evident that, in all such arrangements, the close contact of the primary and secondary coil, with nothing intervening but a comparatively poor insulator in the shape of cotton thread, cannot possibly present an instrument by means of which electricity of high tension could be isolated. In fact, the early construction and use of such machines was entirely confined, as already mentioned, to experimental demonstration at the lecture-table, or to the administration of medical electricity in place of the old method, in which frictional elec-

tricity alone was employed. Approximation to a more perfect instrument was made by Masson and Breguet ; and they, in part, succeeded in converting the quantity of the voltaic current into the intensity of frictional electricity ; or, as it may more philosophically be stated, the voltaic current, by its dynamic force, was rendered available for the development of static induction, by means of a secondary coil wound over a primary, the two being carefully insulated.

Rhümkorf perceived the defects of the early forms of the coil machine. As already pointed out, the wire employed in such was simply coated with cotton in the majority of instruments, silk being far too expensive a material to have been used, considering the comparatively low price at which they were sold. But he employed silk to coat the wire, and also covered that comparatively good insulating medium with a solution of shell-lac. Care was taken also to insulate each fold of the coil. The terminal ends of the secondary coil were affixed to glass pillars ; and the material on which the coil was wound, or, at all events, its ends, were made of glass. Such was the form in which we received our first Rhümkorf from that maker. Mr. Noad, who, with ourselves, was amongst the first to possess such an instrument, remarks—" He, moreover, diminished the diameter of the coil, thereby, with the same quantity of wire, obtaining a greater number of convolutions ; and he greatly increased the length of the secondary, extending it, in some of his machines, to the length of nearly six miles. Lastly, from a conviction that the magnetic current was more effectual in arousing an induced current than the mere coil—that is, that the secondary effects were referrible more to *magneto-* than to *volta*-electric induction—he gave in his coils a great development to the former, by introducing into the axis of the primary a large bundle of iron wires, which he found to acquire a much higher degree of magnetism than an equal weight of iron in the form of an iron bar. To interrupt the inducing current, he employed a simple piece of mechanism known as ' Neef's' hammer, consisting of a small block of iron, which vibrated between the projecting end of the coil of iron wires and a small anvil connected with the primary coil, in such a way that when the anvil and hammer were in contact the current was *on*, but the moment they separated it was *off*. It will be unnecessary to describe minutely this form of contact-breaker, as it has given place to other and far more efficient arrangements. With these improvements, Rhümkorf obtained effects which were, at that time, surprising ; he not only got brilliant sparks between the terminals of the secondary wire, but between the wire itself and a body out of the circuit in communication with the earth ; and he obtained a discharge, in a vacuous globe, of great brilliancy, the spark filling the balloon with that magnificent phenomenon, stratified light, about which we shall have more to say presently. These effects were greatly exalted in degree, by interposing, in the circuit of the primary, a simple condenser, as recommended by M. Fizeau. Brilliant and crepitative sparks in free air were obtained, three-quarters of an inch long," and violent shocks. Mr. Noad somewhat ridicules the accounts of the intensity of the shocks so imparted ; but we can only add, that on two occasions, through incautiousness, we were struck to the ground by receiving a shock from a coil—the shock not only being disagreeable, but harmful. On one occasion, a wire, accidentally held in the hand, fell across the exterior of one coil in full action. The effect on the whole system was to make it appear that the entire body was a mass of light. It is true that our skin is generally moist ; and this may fully account for feeling a greater intensity of shock than those possessing an habitually dry skin ; for, as already pointed out, the communication of a shock from an ordinary coil machine, is greatly facilitated by moistening the hands with water, or a solution of salt.

The following cut represents an ordinary form of one of these Rhümkorf, inductoria, or induction coils. Externally it does not greatly differ in appearance from an ordinary coil machine ; but, in reality, the difference of detail is great. As already stated, the secondary coil is of great length. There were various other arrangements in the original Rhümkorf, differing from the preceding coils. The contact-breaker, for example, has been mentioned as varying from those previously used. In the following cut is a view of the commutator, and its handle. A represents a piece of ivory having two metal sides, turned by the handle, B. In the cut the metal sides are shown as touching two metal springs, only one of which is seen. In this condition the current from the battery to the primary coil of the arrangement is passing.

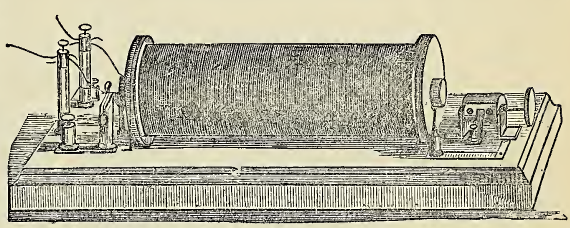


Fig. 217.—Rhümkorf's Coil.

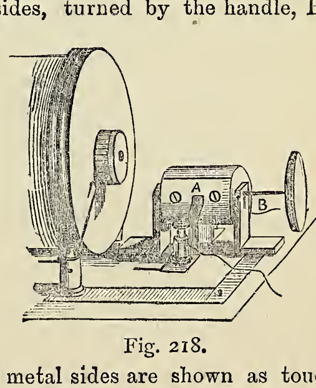


Fig. 218.

But if B be turned round through 90°, then the ivory sides will touch the springs, and the battery current will be cut off from the coil. This arrangement is necessary to prevent the operator receiving a shock in starting or stopping the action of the coil.

In the following cut, the contact-breaker, as originally used, is illustrated. B B are the terminals of the fine coil, supported on two glass insulating pillars, P P. The wires carrying the battery current are represented at A A; and just beneath the extremity of the cylinder of iron wires forming the axis of the coil, will be seen the contact-breaker, already described as Neef's hammer arrangement, at p. 403, *ante*.

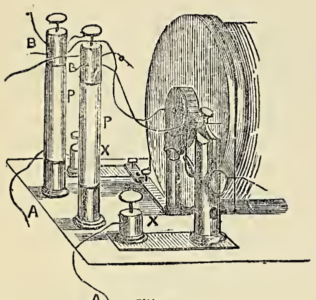


Fig. 219.

The usual battery arrangement most successful in exciting a Rhümkorf coil, is one of four cells of any form of nitric acid battery. We prefer four of Grove's, each platina being $4 \times 2\frac{1}{2}$ inches, in active surface; but, as we shall see hereafter, the battery power must be carefully regulated to the power of the coil, or the latter may be permanently injured. A purchaser of a coil will generally receive a description of the amount of battery power that can be safely employed, as such will entirely depend on the length and thickness of the primary coil, and the length of the secondary. No matter what form of coil is used, the Rhümkorf, as originally constructed, or its improved form (yet to be described), it is always advisable to allow an intermission of a minute or two between trying experiments of some duration, because, as already pointed out at p. 392, *ante*, the resistance of the primary coil may be so great as to cause it to heat—a circumstance highly prejudicial to a continued good action of the instrument.

As already stated, improvements were speedily suggested on the original of Rhümkorf; Mr. Hearder, of Plymouth, the celebrated electrician, leading the way. His secondary coil was about a mile and a-half long, and "was covered with silk, and the layers insulated from each other with oiled silk and gutta-percha; it was provided with a condenser, gave sparks between the terminals more than one inch in length, and charged a Leyden jar containing three square feet of surface, so as to give a torrent of brilliant discharges between platinum terminals. For this instrument Mr. Hearder received the Society's first silver medal.

In September, 1856, Mr. Charles Bentley showed the writer a coil of his own construction, which gave sparks between terminals of silk-covered wire an inch and a-half long, the primary being excited by five of Grove's cells. In building up this coil, he used, as an axis, a hollow iron tube, nine or ten inches in length, and half an inch in diameter; round this he arranged a considerable number of insulated wires, the same length as the tube, and sufficiently numerous to form a bundle of an inch and three-quarters in diameter. This core was insulated by being covered with six or eight layers of waxed silk. Thirty yards of No. 14 cotton-covered copper wire were then wound carefully round the iron core, forming two layers, which were then insulated from each other by eight thicknesses of waxed silk. The secondary wire consisted of 3,000 yards of No. 35 silk-covered copper wire, and the coils which it formed were insulated by several layers of gutta-percha tissue; it was wound so as to leave a space of about one-sixteenth of an inch at either end of the coil beneath, so that it formed a cylinder with rounded ends—a form preferred, from its obviating the necessity of glass checks for keeping the wire in its place. The condenser, which was contained in a separate box, consisted of 100 sheets of tinfoil, 4×9 inches, each sheet of foil being placed between two sheets of carefully-varnished paper, and the alternate ends were connected.

Through the kindness of Dr. Noad, we had the pleasure of seeing Mr. Bentley's instrument in action at the period just referred to. In all respects it was a great improvement on Rhümkorf's original, the sparks and other phenomena being much larger.

At a lecture given by Mr. Noad, about the preceding date, at the Polytechnic Institution, London, Rhümkorf's coil was compared, by experiment, with Mr. Bentley's improved form, and the latter gave great satisfaction to many scientific gentlemen who were present.

Many of the instrument-makers of London, Edinburgh, &c., have since carried improvements still further; amongst whom we may especially name Mr. Ladd, of the metropolis, and Mr. Hart, of Edinburgh.

For the following description of the induction coil, as constructed by Mr. Ladd, we are indebted to a work by Mr. Noad, already quoted. "The coil consists of the usual primary, which is covered copper wire, 0·10 inch in diameter, or No. 12 wire gauge, wound with a coil of three thicknesses, enclosing a bundle of iron wires, 1·8 inch in diameter. The ends of this bundle project 0·7 inch beyond the gutta-percha ends, which are seven inches in diameter, and 0·6 inch thick: these gutta-percha discs are firmly fixed on the base-board of the machine, and serve both to support and insulate the coil. The secondary coil is made of No. 35 gauge wire, three miles long. It is very carefully wound round the primary in about thirty layers, each layer being insulated from its neighbour by a

sheet of gutta-percha. The total length of the coil is eleven inches, and its diameter, including the velvet jacket, is five inches. The ends of the secondary coil pass through one of the terminal gutta-percha discs to an insulated discharger, the arms of which move in ball and socket joints, so that the terminals may be separated any distance from one another up to about four inches." This we consider a great improvement on the original method, which is illustrated at p. 404, *ante;* for, by this arrangement, the distance between the terminals or poles of the secondary coil can be regulated with ease and certainty; whereas, in the old form, much difficulty was experienced in so doing.

"The arm in connection with the wire proceeding from the interior of the coil is provided with an ivory handle, by which the arm may be moved; the other arm, in connection with the *exterior*, terminates in a brass knob; this must not be touched while the machine is in action, if the operator wishes to avoid a powerful and painful shock. One of the ends of the primary is brought out through the anterior, and the other through the posterior gutta-percha disc, to two brass studs, from which they are conducted underneath the wooden base to the commutator and the contact-breaker. The wires from the battery (five pairs of Grove's arrangement, immersed platinum $5\frac{1}{2} \times 3$ inches) are attached to two binding-screws, one on either side of the commutator, as shown in p. 403, *ante*. The condenser is conveniently placed in a box underneath the base of the instrument, to which it is firmly attached. It is composed of about fifty sheets of tinfoil, 18 $\times$ 8 inches, and between each sheet is laid a sheet of varnished paper; one-half of the foil is in metallic connection with each side of the break, so that when contact is broken, the interrupted ends are respectively in metallic communication with the opposite coatings of the condenser.

"The contact-breaker merits especial notice, as it is to the improvements introduced into this part of the apparatus that the surprising effects of the coils of the present day are, in a great measure, to be ascribed. In Rhümkorf's original instrument, the interruption of the battery current was, as we have seen, effected by the rising and falling of a small iron hammer; this, whilst it accomplished the general purpose of breaking and renewing battery contact, set up no resistance, the hammer being raised as soon as the iron core had received sufficient magnetism to enable it to attract a very small piece of iron; whilst the falling of the hammer, on the interruption of the current, was in no way influenced by the degree of magnetisation of the iron core."

We believe that we first pointed this fact out, and overcame the difficulty in the original Rhümkorf, by weighting the hammer with a glass rod. But Mr. Ladd's method is such, that the degree of resistance to the attractive force of the magnetised iron wires forming the centre of the coil, may be regulated at will. The necessity of this will be apparent from what has been already stated—that time is an element in the production and destruction of magnetism induced by electric currents on soft iron. Mr. Ladd accomplishes the object by using a stiff spring, to which the hammer of the contact-breaker is attached; and by means of a screw, the stiffness or resistance of this spring can be regulated at pleasure. The consequence of this is, that the length of the secondary spark may also be regulated; for just as, within certain limits, the motion of the contact-breaker is restrained, so the length and noise of the sparks are increased until a maximum of any coil's powers is obtained.

The results of the various improvements have been to enormously increase the length of spark. Our early Rhümkorf gave, in the air, sparks rarely, under the best circumstances, more than an inch and a-half to two inches long; now sparks above a foot long have been obtained. The condenser, which has already been described as formed of folds of tinfoil and oiled silk, paper, or other non-conductors, has a great influence on the length of spark. Its exact office has not been satisfactorily explained. Faraday's opinion was, that "when the secondary current was interrupted, the inducing power of the primary current acts in its own wire to produce certain hurtful and wasteful results. [We have already shown, that besides the voltaic current passing along the primary, another current is produced by its own induction.] The condenser takes up this extra power at the moment of time, and converts it into a useful final purpose, upon principles belonging to static induction." Various other opinions have been offered, but still the action or function of the condenser remains to be properly understood. Having thus explained the principles of the construction of the induction coil, or inductorium, we next proceed to suggest various experiments by which many beautiful effects may be exhibited.

First in order is the production of the spark in air. As already stated, for all ordinary purposes, four cells of Grove's platina battery make the best voltaic arrangement for exciting the coil. Each platina may expose a surface of about twelve square inches. The porous cells holding the platina are charged by ordinary strong nitric acid, or a mixture of the acid with an equal portion of sulphuric acid. The two acids should first be mixed in a porcelain vessel, as they evolve great heat, and in a place where the suffocating fumes can be quickly carried off. The mixture must be allowed to cool before being poured into the cells.

The zinc side may be charged with a mixture of one part of sulphuric acid to eight of water, or one part of hydrochloric acid to three of water; the zinc, of course, must be amalgamated. If the hydrochloric acid be used, chloride of zinc is formed; and this may be used for a long time, successively, as an excitant of the zinc, in place of acids. The zinc need not be amalgamated again after first use if this solution be employed. Hence time, trouble, and expense are all saved.

The two wires of the battery are then to be attached to the binding-screws of the primary coil, care being taken that the commutator (already described at p. 404, *ante*, and illustrated by Fig. 219) is so placed, that the current for the present shall not enter the primary coil; for a careless operator, if he neglect this precaution, and venture to regulate the distance of the secondary terminals, may find himself on the ground, through receiving a violent shock.

The terminals of the secondary being adjusted at a distance of from one to four inches, the commutator may be turned so as to send the current into the primary coil. Immediately flashes of light, resembling minute flashes of lightning, will pass between the terminals, accompanied with a loud snapping noise. By increasing or decreasing the distance of the terminals (before doing which turn off the current), a vast variety of changes will be seen in the colour, shape, &c., of the flame. It will be noticed that the apex of the two terminals presents at each a very different appearance; and if the terminals be each a thin platina wire, one of these, according to the direction of the current, will become red-hot, whilst the other shows no signs of heat.

By turning the commutator, the phenomena exhibited at each terminal are reversed; the heated end will appear at the contrary terminal. In place of platina wire (which will only get hot, or perhaps fuse), one of magnesium, iron, or zinc may be employed, when a brilliant light and combustion will be afforded, forming a beautiful spectacle, especially with the magnesium wire, which gives brilliant results.

If a piece of paper be placed in the flashes of light and flame, the heat developed will be sufficient to ignite it.

The following experiments we have neither seen nor tried: they are suggested in Mr. Noad's work; and we shall take the liberty of quoting from it:—"Attach iron-filings to a large pane of glass, by means of a suitable varnish [solution of shell-lac in spirits of wine will answer], and, when dry, place it between the terminals; flashes of light, more than a foot in length, may be obtained. Moisten a piece of cork, ten inches long and four inches wide, with dilute sulphuric acid; place the terminals upon it, at first about two inches apart. Great heat will be set up on the line of discharge, which will vaporise the water, and the cork, becoming charred by the sulphuric acid, will begin to burn; now slowly separate the terminals, drawing one along the surface of the cork in a zigzag manner; the flame will follow it, charring the cork in its progress, and leaving behind a line of light. In this way you may proceed from one end of the cork to the other, making a complete lake of fire, which has, in the dark, a very beautiful appearance. The best way of making the experiment is to lay the cork upon the table, and stick into one end a wire in connection with the inner terminal of the coil; a wire, leading from the outer terminal, is attached to a brass rod, provided with a varnished glass handle, and to this a stout wire; the operator directs the wire along the cork, by this contrivance, without the chance of getting a shock. If a sheet of silvered leather be substituted for the cork, it becomes brilliantly illuminated with a green-coloured light; or if common leather be moistened with dilute sulphuric acid, it may be used instead of cork. It must be observed that both cork and leather, after having once been rendered conducting by acid, retain their conducting power for a long time after they have become dry.

"Separate the arms of the discharger beyond the striking distance; in the dark, brushes of light will be seen to dart from the positive electrode, and the negative will be illuminated by a characteristic star of light, also throwing off smaller brushes, which re-curve over the wire.

"In liquids of good conducting power no spark can, of course, be obtained; but in *non* or imperfectly conducting fluids, short crepitating sparks pass. In oils these sparks have a greenish-white colour; in alcohol they are red and crepitating; in oil of turpentine, and in bisulphide of carbon, they are very brilliant. Pour some oil on the surface of water in a glass vessel; introduce a wire covered with gutta-percha, and proceeding from the interior of the coil, underneath the water, just below the oil; and plunge a protected wire from the other extremity within striking distance in the oil; strong crepitating sparks are obtained, and hydrogen gas is liberated, which burns on the surface of the liquid."

Numerous interesting results with the spark will suggest themselves as the operator repeats the preceding and other experiments, so far as they are conducted in the air.

The heating effect has been turned to good account for blasting gunpowder, as may be illustrated as follows. Insert two wires in a gutta-percha tube, the ends of each being left half an inch apart in the tube. Fill this with gunpowder, and the two wires are then to be attached to the secondary wires of the coil. If the primary current be now turned on, the gunpowder will at once explode.

The resistance which the atmosphere affords to the passage of the current is very great. The same fact is noticed in respect to the sparks of frictional electricity; for, whilst a powerful machine will not give sparks more than a few inches long in the atmosphere, in a vacuum the length will extend to as many feet. The experiments with an induction coil, with the spark in a vacuum, are of the most beautiful character, and will shortly be considered in full detail.

Meanwhile, the lengthening effect on the spark, resulting from heating the air intermediate between the terminals, may be strikingly illustrated as follows:—Remove apart the two terminals to such a distance that the sparks only occasionally pass. Now interpose a wide flame from a spirit-lamp between them: the torrent of sparks will be at once restored. An ingenious modification of the experiment may be obtained by placing a number of lighted spirit-lamps side by side, when the discharge will take place from

one flame to the other, between the two terminals, over a distance of many inches.

Some of the most beautiful of the phenomena exhibited by the coil, is Gassiot's cascade. To show this, a beaker-glass, about three inches high and two wide, is coated internally with tinfoil, leaving an inch uncoated from the top. This is then to be placed on the plate of an air-pump. The following engraving illustrates the method

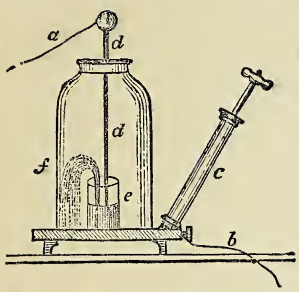


Fig. 220.—Gassiot's Cascade.

of carrying out this splendid experiment. *a* is a wire proceeding from one end of the secondary coil: it is attached to a knob connected with a brass rod fitting air-tight to a glass receiver, and reaches into, touching the bottom of, the coated beaker-glass, *e*. The handle of the pump is seen at *d*, and the wire, *b*, is connected with the other terminal of the secondary coil. The air is then to be exhausted as completely as possible from the receiver. The more complete the vacuum that is obtained, the more beautiful will be the effect. When the vacuum is complete, the commutator of the coil is turned on. A magnificent purple cascade of flame, *f*, will instantly pass. With a good vacuum the flame is of a rich purple colour: by reversing the direction of the current in the primary coil, the cascade will appear to flow into the beaker from the metallic plate of the air-pump.

Another method of performing this experiment is to connect the wires as above shown, and to turn on the current before exhaustion is effected. As the process of exhaustion is carried on, an occasional blue spark will pass; as a vacuum is gradually attained, the cascade will make its appearance, until, with the best possible vacuum, the full effect results.

Another method of showing the discharge in an exhauster receiver is shown in Fig. 221; the receiver being similar to that employed in experiments with frictional electricity in a vacuum.

In our early experiments, we turned this vacuum spark to the purpose of decomposing vapours, by pouring a little bisulphide of carbon, etc., etc., into the beaker. A still better plan is described as follows, by Mr. Noad:—

"*Decomposition of Gaseous Compounds.*—When the spark-current from the induction coil is sent through ammonia, it exhibits a violet light, surrounded with a blue edge. At first the mercury over which the gas is confined falls rapidly, the rate of expansion diminishing with the progress of the decomposition; in five minutes the decomposition of a moderate volume of ammonia is accomplished. The original volume is then doubled; the spark current exhibits the pure violet light characteristic of hydrogen, and water injected into the tube produces no diminution of volume. The coil thus becomes a valuable instrument for demonstrating the composition of this interesting gaseous alkali in the lecture-room. For the introduction of the spark-current through this and other gaseous compounds, a simple arrangement was contrived by Buff and Hofmann. A fine platinum wire is fused into the shorter limb of a thin U-shaped glass tube, and filed off so as scarcely to project beyond the glass. At a distance of a few millimetres from the platinum pole thus obtained, the loop of a second platinum wire is thrown over the tube, and the wire wound round the tube until it nearly reaches the bend. The tube is then filled with mercury, and the shorter limb introduced into the graduated glass tube inverted over mercury in a deep cylinder trough. The pole wires of the induction coil being now introduced, the one into the open end of the U-tube filled with mercury, and the other into the mercury of the cylinder trough, the spark-current may be established or interrupted at will, by either depressing the U-tube until the outer platinum wire reaches the mercury surface, or by lifting it so as to break contact. Occasionally Buff and Hofmann effected the decompositions by incandescent coils of iron or platinum, or by the electric arc. For experiments of this nature, both limbs of the U-tube remain open. The iron or platinum wire is inserted into the shorter limb, and then coiled downwards round the tube. Since the powerful heat emitted from the coil is apt to crack the U-tube, it was found convenient to surround the latter with a somewhat wider glass tube."

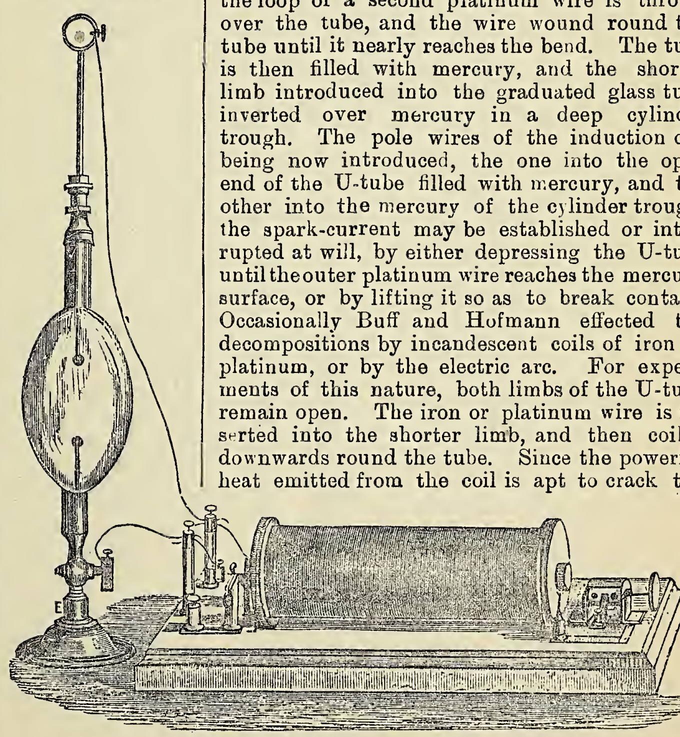


Fig. 221.—Vacuum Discharge.

Nitric oxide was decomposed *slowly* by the spark-current, *rapidly* by the incandescent iron coil, the iron burning with splendid scintillations; the residual volume of nitrogen was one-half the original volume of gas. Through dry *carbonic oxide* the spark-current passes with a blue light, but without effect; nor was this gas decomposed either by the incandescent coil or by the electric arc. *Carbonic acid* was decomposed by the spark-current into carbonic oxide and oxygen; the mixture then exploded, re-forming carbonic acid: unfortunately the decomposition is too slow for a lecture experiment; the colour of the spark in the gas is violet. *Marsh gas* was partially decomposed by the spark-current, ten volumes of the gas becoming, in half-an-hour, eighteen volumes, and the colour of the spark changing from pale blue to violet. *Olefiant gas* was decomposed by the spark-current, which traversed the gas with a pale red light, into carbon and hydrogen; after about twenty minutes, seven volumes of the gas became $12\frac{1}{4}$; had the decomposition been perfect, the volume should have been doubled. *Sulphuretted* and *phosphoretted hydrogen* were both rapidly decomposed by the spark-current, the former with the deposition of sulphur, the latter with that of phosphorus, in the form of a brown powder. These results are sufficient to show what a powerful, elegant, and useful agent of gaseous analysis the induction coil is likely to become."

The experiments in vacuo are exceedingly well carried on in what are termed vacuum tubes, which will be presently described. In the following engraving is an apparatus, which we introduced some years ago, for the purpose of showing the spark over a cistern of mercury in a barometer tube.

a is an ordinary barometer tube, into the top of which is to be introduced, air-tight, by melting the glass, a platina wire, *d*. The tube should be about thirty-six inches long. It is to be filled with clean, well-boiled mercury, and inverted, with its lower end in *b*, a cistern of mercury. An interval, *c*, will then occur, which is a barometrical vacuum, the length of which will depend on the varying conditions of atmospheric pressure. To maintain the tube in an upright position it is to be affixed to a support, *e e*, in a manner represented in the engraving. An ordinary laboratory retort-stand answers well for the purpose. One wire of the secondary coil is to be connected with the mercury in *b*, and the other extremity of the coil is to be connected with the platina wire, *d*, at the top of the tube. On turning on the primary current, a discharge of pale lavender light will occur between *d* and the mercury in *a*. The colour of the light, in this case, is doubtless due to minute portions of the vapour of the metal mercury occupying the supposed vacuum at the top of the tube.

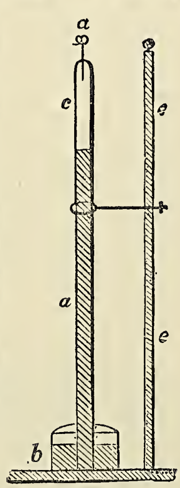


Fig. 222.

The discharge of light is characterised by most singular bands, resembling such as are seen on the body of a leech. If the pole of a magnet be presented to it, external, of course, to the glass tube, the phenomena of repulsion, &c., may be readily noticed; so that, apparently, a band of light becomes obedient to the action of magnetism. A reversal of the direction of the current is, of course, easily effected by reversing the commutator, so as to change the direction of the primary coil-current.

In connection with the action of the magnet on the band of light, the celebrated electrician, De La Rive, has suggested the following experiment:—"Place the pole of a powerful electro-magnet underneath the surface of mercury connected with the negative pole of a powerful voltaic battery. Bring over, and near it, the positive pole, armed with a charcoal point. A voltaic arc is formed [after contact], and the mercury is agitated above the magnet; luminous currents rotate round the pole, throwing out, occasionally, brilliant rays. The phenomena of the rotation of electric light round a magnetic pole may be exhibited in a most superb manner thus:—Into the brass cup of a large globular or egg-shaped glass receiver, a soft iron bar, surrounded with a coil of covered copper wire, is fixed; the receiver is then to be exhausted. On sending the induced current [from an induction coil] through the exhausted receiver, a splendid band, or riband, of purple light makes its appearance, and immediately commences rotating round the iron rod, when that is converted into an electro-magnet by sending the current from a small voltaic battery through its surrounding coil. On turning the commutator so as to change the direction of the induced current, the direction of the rotation changes also. In this truly magnificent experiment the electric light takes the place of the revolving conductor in Faraday's discovery."

For experiments in illustration of the production of an appearance resembling the aurora borealis, long tubes are employed, that have been exhausted of air, and a stream of frictional electricity is passed through, when a rich purple flame is produced. The induction coil answers precisely the same purpose. Indeed, by means of the coil already described at p. 403, *ante*, we have succeeded in producing such phenomena in a manner little inferior to those afforded by the powerful hydro-electric machine, formerly in the Polytechnic Institution, Regent Street, London. But the effect is generally inferior to that obtained by the vacuum of an air-pump, simply because it is impossible to get anything like so good a vacuum in a long tube, and equally so to maintain it. Still a long tube may be screwed into the plate of an air-pump, and the exhaustion constantly kept up by pumping. As already mentioned at p. 407, *ante*, as the vacuum decreases, so does the beauty of the effect, both of the frictional electric and inductive coil discharge.

We are indebted to Mr. Noad's work, already frequently quoted, for an account of one of the most beautiful experiments with the induction coil:—

"A glass tube, not less than eighteen inches long by three inches in diameter, is provided with a brass ball at the top, attached to the ordinary flat brass plate and sliding-wire ; and at the bottom with a small metal cup, half an inch in diameter, attached to the nipple of the air-pump plate. This is to contain a piece of thoroughly dry phosphorus, about the size of half a pea ; and the tube, after being rubbed inside with a warm cloth to insure the absence of moisture, is placed on the plate of the air-pump, and the top with the brass ball adjusted on it : after getting a good vacuum, the phosphorus will begin to glow, and contact with the coil should be made in the usual way ; that is, the upper part of the tube should be connected, by means of a fine wire, with the arm of the instrument that is not provided with an ivory holder, and the other arm with the brass-work of the air-pump. It is very necessary in this, as, indeed, in all experiments with the induction coil, that the connection should be carefully secured, in order that no wire should become displaced when the room is darkened, and so endanger the operator. Contact being thus established, and the phosphorus allowed to glow for about five minutes, the commutator may be turned on ; the phosphorus will then, by means of the electric spark, show signs of ignition, and the stream of electricity will become brilliantly stratified ; then, on continuing to work the extra barrel of the air-pump, the light will become wider, and fill the whole tube. Should the phosphorus at '' , commencement of the experiment have shown sufficient activity, the stream of electricity will now begin to assume a faint salmon colour, the stratification becoming still more brilliant until the colour becomes white or silver, and the effect, to a close observer, gorgeous in the extreme.

"The changes of motion and form are produced by means of the screw attached to the break, by reversing the commutator, and by varying the power of the battery ; but they are by no means certain.

"It appears to be important for the success of this beautiful experiment, that the phosphorus, after a good vacuum has been obtained, should be well ignited by the electric current ; but this does not generally happen when the exhaustion has been carried too far ; it is equally necessary that the vapour from the phosphorus be not too much deposited on the surface of the glass tube so as to obstruct the view, which would happen were the phosphorus too soon ignited.

"Sometimes the effect produced is that of a number of cones of light chasing each other from below upwards, and *vice versâ ;* sometimes they are flat tables of light, an inch or more apart ; sometimes they are rings apparently revolving or oscillating, and vanishing one into the other ; and not unfrequently the whole mass assumes the form of a cloud, with no motion whatever ; sometimes there are two clouds ; and the effect of intercepting the current for a minute or so is to bring back the stratification, which lasts but for a very short time, and the cloud remains as before, resisting all endeavours to produce stratification, except for two or three seconds after the current is turned on. A very common effect is the formation of one large column of little cones in rapid motion, filling the whole tube, and reminding one of the ripple of the sea by moonlight ; and, again, four or five streams of cones filling the tube from end to end, all at the same time.

"On more than one occasion, after varying the effects for upwards of an hour, I have succeeded in obtaining from sixteen to twenty layers of stratification, each layer being composed of two colours distinctly divided in the centre, the upper half green, the lower magenta, and *vice versâ*, according to the directions of the current, exhibiting an effect similar to the very beautiful experiment in vacuo produced by Mr. Gassiot with his large battery.

"If, at the conclusion of these experiments, a small quantity of air be admitted into the tube, the effect will be extremely beautiful ; it should be done as quickly as possible, and instantly checked ; unless too much air has been admitted, the stratification will not be destroyed, but a brilliant stream of magenta-coloured light will gradually blend with the whole : it is not always, however, that the original silver colour can be again restored."

(We have already pointed out the varying effects that may be obtained by the amount of air that may be present in a so-called vacuum tube. The experiment we have suggested with the barometer tube gave a flame or luminous discharge of a light lavender tint, due, most probably, to the slight amount of mercurial vapour created by the discharge. In using the hydro-electric machine, or ten-foot plate machine, described under the head of Frictional Electricity, the discharge gave, in a partial vacuum, only a spark or ball-like discharge, which became of a stream-like character, as the vacuum increased.)

We continue our quotation from Dr. Noad :—

"These effects, which can be shown with still more magnificence in a larger tube, are continually varied.

"Some beautiful results are obtained by experimenting with alcohol, wood-spirit, or turpentine vacua. When the poles are five or six inches apart, two distinct lights are produced, differing in colour, form, and position. That round the negative ball and wire is blue—it envelops it regularly ; that round the positive is fire-red—it adheres to one side, and stretches across towards the negative, and has for its lateral limits a surface of revolution about the axis of the receiver. On close examination, this double light is seen to have a singular constitution ; it is stratified, being composed of a series of brilliant bands, separated from each other by dark bands. In a good vacuum, the appearance is that of a pile of electric light. In the red light, the brilliant bands approaching nearest to the negative ball have the form of capsules, the concave part being

turned towards the ball; their position and figure are sensibly fixed, so that it is easy to see that there is a solution of continuity in passing from one to another. The extreme capsule does not touch the violet light of the negative pole, being separated from it by a dark band, greater or less, according to the nature and perfection of the vacuum—that with spirits of turpentine giving the greatest. It was found by M. Quet, that when a galvanometer was interposed in the current, no current was indicated as passing through the electric egg till the exhaustion was literally good, and the light continuous; the needle then became permanently deflected. A light, though less brilliant, may be obtained from one pole only—that of the exterior wire of the secondary coil, which possesses electricity of the highest tension; and if the vacuum be very good, the light may be made to bifurcate [or split in two], by placing the finger against the outside of the glass. If currents from two coils be made to circulate in opposite directions through the receiver, the red light disappears from the positive pole, giving place to a blue light: the positive and negative lights are now identical. The same occurs when a resistance is introduced into the induced circuit, as by interposing a condenser between one of the poles and one of the balls of the egg. A uniform blue light is thus obtained round both balls, which, with a very good exhaustion, may be stratified."

Mr. Noad, in his *Treatise on the Inductorium*, pp. 71, 72, remarks—"In the barometrical vacuum, previous to the researches of Mr. Gassiot, detailed in the Bakerian lecture (March 4th, 1858), *no striæ had been observed*, the induction spark being white, and filling the tube. By making these vacua, however, with great care, Mr. Gassiot has succeeded in obtaining stratification very distinct, and well defined."

To this statement we emphatically demur. So early as August, 1856, we showed, at the lecture-table at the Polytechnic Institution, Regent Street, such striæ; and our late deceased friend, Dr. Normandy, was one of the first, with ourselves, to notice the fact. The experiments were made with a barometer tube, exactly like that illustrated by Fig. 222, p. 408, *ante;* and, indeed, that engraving was taken from the apparatus so employed. Should these lines meet the eye of Mr. Noad, he will remember having given a lecture at that institution in a following month, long after this and other experiments had been exhibited in public at that place. Faraday himself saw the experiment, as we then carried it out in 1856; and, at a shortly previous date, employed an arrangement for getting the Leyden discharge from the induction that we had constructed, and which will shortly be described. So early as in the preceding May, on the occasion of her Majesty visiting the Polytechnic, we had prepared such an arrangement of the barometrical tube; and it would then have been used by Faraday, but for press of time in respect to the variety of matters that had to be passed through during the evening of her Majesty's visit.

The experiments with vacuum tubes are too numerous to detail. Almost every philosophical instrument-maker has his own special form. Some of them are illustrated in the following cuts, and many others may be seen in the instrument-makers' windows.

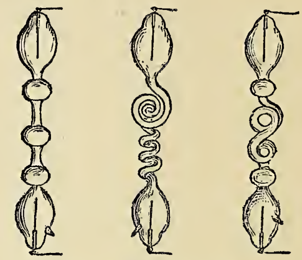


Fig. 223.—Vacuum Tubes.

The effect of an attenuated atmosphere of various gases, as hydrogen, nitrogen, &c., is very curious, and, at times, beautiful. In fact, a variety of the most attractive effects to the eye, may be produced by the discharge of the induction coil through attenuated gases, coloured glass tubes, from various solids, &c., that our space will not permit us to describe. In connection with a spectroscope, such as is used for spectrum analysis, results of a most interesting philosophical character are also afforded; but into those we cannot here enter, as they relate more particularly to chemical science.

The Leyden Discharge.—By means of a Leyden jar, or battery, a complete torrent of sparks, affording a deafening noise, may be kept up, attended with luminous calorific, mechanical, and other effects. A simple apparatus, that we first fitted up about twenty years ago, answers very well, as showing these results, and is represented in the following cut. *a* is an ordinary

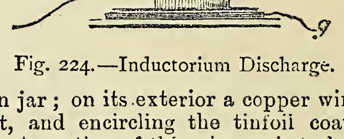


Fig. 224.—Inductorium Discharge.

Leyden jar; on its exterior a copper wire, *b*, in contact, and encircling the tinfoil coating, is fixed. A portion of this wire, *c*, is to be curved round, so as to nearly, but not quite, touch the knob, *d*; *e* is a wire attached to the end of the inside of the secondary wire of the induction coil, and is connected with *b c*; whilst *f* is a wire attached to the outside end of the secondary coil, and twisted round the brass rod of the knob, communicating also with the inner coating of the Leyden jar. The whole is rested on a gutta-percha, ebonite, glass, or other non-conducting material, *g*.

If the current be turned on to the primary coil, and the wire, *c*, be distant, at its end, about an eighth of an inch from the knob, *d*, a constant series of discharges will take place, the noise and light of which are overpowering.

If a card be introduced between the part of the wire, *c*, and the knob, *d*, it will be instantly perforated; spirits of wine, naphtha, &c., may be also ignited.

We have similarly charged a Leyden battery that exposed seventy square feet of surface, and the effects were very remarkable. Most of the class experiments generally exhibited, in connection with static or frictional electricity—such as the repulsion, &c., of both balls—may equally as well be exhibited by means of the induction coil.

In a similar way, the decomposition of water, saline solutions, electro-magnetic phenomena, &c., &c., may be effected by the coil. As already stated, the induction coil affords a link between static and dynamic electricity, or that excited by friction, as in the electrical machine, and that of the voltaic current. Hence, apart from the beauty of the phenomena which it gives rise to, in a philosophical point of view, it is one of the most interesting instruments that has been added to science during the present century.

The numerous improvers and investigators of the effects of the coil, almost cause us to forget that we owe it simply to the early researches of Faraday, already described at p. 393, *ante*, when we first dealt with the subject of *volta-electric induction*. How great a matter has such a spark kindled! Glad are we that it was our privilege to hear Faraday expound the variety of phenomena that has been described. One of the largest induction coils that has yet been made was for the Polytechnic Institution. Mr. Spottiswoode has since constructed one still larger. It gives four feet sparks.

ELECTRO-MAGNETISM AS A MOTIVE POWER.

We have already noticed, at p. 397, *ante*, that owing to the element of time entering into the operations of inducing magnetism by the agency of the voltaic current—in other words, that the current does not instantaneously make a magnet; nor does the newly-made magnet instantaneously lose its magnetism—every attempt that has yet been made to render electro-magnetism *directly* a source of motive power has been a failure.

The enormous attractive force engendered by electricity in soft iron, again, as we have shown, extends from the surface of the electro-magnet to but a short distance. At p. 390, *ante*, some experiments that were made by Mr. Watkins were detailed, in respect to interposing plates of exceedingly thin mica between the poles and keeper of an electro-magnet; and, in other pages of this work, frequent mention has been made of the rapid decrement of attraction in all forms of magnets, as the distance is increased between the attracting magnet and the attracted body; although, as stated at p. 370, *ante*, Coulomb showed that the ratio of decrement is, as with all radial forces, inversely as the square of the distance.

But other considerations, besides those of a physical character, interfere with the successful application of electro-magnetism for motive purposes. If we convert water into steam, the liquid becomes expanded, at least, to the extent of 1,600 times its previous bulk; and this is done at a most trifling cost. It must be a badly-contrived steam-engine that cannot afford a horse-power work by the consumption of ten pounds of coal per hour; indeed, at the present day, that power is constantly obtained by the consumption of not more than a third of that amount of fuel. Now a "horse-power" is equivalent to raising 33,000 pounds one foot high in a minute; and this, by such a steam-engine as we have been supposing, is done at the cost of $\frac{1}{60}$th part of the price of ten pounds of coal—a sum so trifling as only to be appreciated by reckoning an ordinary day's working expenses. By improved methods of superheating steam, and expansion gearing, the cost of one-horse-power, in a large steam-engine, is very much less than the lowest amount we have stated.

Reverting now to the cost of electro-magnetic motion, we find an utterly opposed state of things. In the first place, the zinc that is now alone used as the positive element of the battery, is generally worth about £20 per ton. In our manufacturing districts, coal is often only worth about as many pence per ton, and rarely double as much in cost in respect to that used in large factories. Even house-coal, in some parts of Lanarkshire, we have seen sold at 4*s.* 6*d.* per ton. But, besides zinc as the positive element of the battery, there is the sulphuric acid required to excite it. Now, estimating the equivalent of zinc at 32, and of dry or absolute sulphuric acid at 40, it is evident, for every pound of zinc consumed in each battery, there must be required $1\frac{1}{4}$ pound of sulphuric acid. But the strongest commercial sulphuric acid is a compound of one equivalent of sulphuric acid and one of water = 49. Practically, even this represents the acid as far superior to that supplied in commerce; and, taking the matter on an average, we may consider, at the lowest, that for every 3*d.* of zinc consumed, the sulphuric acid costs $1\frac{1}{2}$*d.* more: in all, $4\frac{1}{2}$*d.* for every pound of zinc consumed.

But we have only considered the zinc side of the question. In practice, it has been found, that although Smee's, or a cast-iron and dilute sulphuric acid battery may be used, still that the only really available battery must be some form of the nitric acid kind: such, for example, as Grove's platina, Bunsen's carbon, or Callan's iron arrangements. The reason of this is, that although, theoretically, *one* cell of any battery, affording enough quantity, ought to be sufficient for all electro-magnetic purposes, still, owing to the resistance that the long coils, used in making electro-magnets, afford to the passage of the current, several cells must be employed. At p. 389, *ante*, we have stated that, in experimenting with two of the largest electro-

magnets that have yet been made, it was found necessary to employ no less than fifty cells, to overcome the resistance that even the purest copper wire afforded to the passage of the current.

If, therefore, a nitric acid battery be employed, of course the cost of this very expensive acid must be added to our previous calculation. But, unfortunately, the nitric acid is not *solely* employed, so far as its oxygen is concerned, in uniting with the nascent hydrogen evolved at the negative plate of the battery. If so, every fifty-four parts of the pure acid should be equivalent to the neutralisation of five of hydrogen. But, practically, such is not the case. The moment a nitric acid battery is set to work, the acid begins to evolve binoxide of nitrogen, which, coming in contact with the atmosphere, produces those annoying red fumes so familiar in voltaic experiments. Now, every equivalent of this binoxide, so evolved, shows a dead waste of two equivalents of oxygen. And not only so, ammonia is produced, which, in part, escapes, and a part neutralises the efficiency of the remaining nitric acid in the porous cells ; so that, to use a figurative expression, not only are both ends of the candle alight at the same time, but its sides are simultaneously melted.

A priori, therefore, even to the most unscientific of our readers, it will be evident, that until we can obtain some cheaper method of producing an electro-current, it will be impossible economically to apply electricity as a motive power, at least so far as the voltaic battery is concerned. It is true, that discoveries, very recently made, have shown that, by means of magnetic induction, an enormous amount of dynamic electricity may be obtained, as evidenced by Mr. Wilde's application of such methods to the production of a brilliant light; as also of Mr. Holmes' plan. By similar means electricity has been converted into a motive force, as will be subsequently explained.

A century has scarcely elapsed since steam, as a motive power, was unknown ; and yet, at this day, it is an absolute necessary of daily life. It was only at the commencement of the present century that gas was thought of as an illuminating agent; whilst now, its absence would be considered as a dire social calamity. Thirty years ago, coal-tar and gas-house liquor were considered not only as absolutely valueless, but as a nuisance; whilst, at this day, they afford products worth more than their weight in gold. We therefore do not here predicate what may be, but simply state things as they now are ; and but add, that the realisation of some form of electricity as a new motive power, is not only feasible, but has been accomplished, yet only under other conditions or circumstances than formerly existed.

Dumont (*Comp. Rendus*, August, 1851), remarks, as the result of his experimental investigations of the subject, that—

"1. The electro-magnetic force, though it cannot yet be compared to the force of steam in the production of great power, either as it regards the absolute amount of power produced, or the expense, may, nevertheless, in certain circumstances, be usefully and practically applied.

"2. While, in the development of great power, the electro-magnetic force is very inferior to that of steam, it becomes equal, and even superior to it in the production of small forces, which may thus be sub-divided, varied, and introduced into trades and occupations using but small capital, where the absolute amount of mechanical power is of less consequence than the facility of producing it instantaneously, and at will. In this point of view, the electro-magnetic force assists, as it were, the usefulness of steam, in the place of uselessly competing with it.

"3. Other things being proportional, electro-magnetic machines, with direct attracting movement, present a great superiority of the power developed over rotating machines ; since, in the first, there are no components lost; and, with the same expense, a much more considerable power is obtained than with the rotating machines.

"4. In machines of direct movement, the influence of the currents of induction appears less considerable than in rotating machines."

Although the preceding remarks were penned some years ago, still they very fairly state the facts of the case. Mr. Joule, and others, have done much to elucidate both the scientific principles and economic facts of the case ; but still, in the year 1879, the practical part of the subject was not advanced an iota in value, mechanically, than it was at the day Faraday first discovered the phenomena of volta and magneto-electric induction. It hence follows, that all we need do is to state what has been effected in various ways, and by many ingenious inventors, in the hope of making electro-magnetism of use for producing motive force.

The forms of the machines, as already hinted, may be divided into two classes—viz., those in which the motion is communicated by vibration, or other similar action, and such as are of a rotatory character. The special characteristics of each of these will be best understood by referring to examples.

The annexed cut represents an arrangement in which an electro-magnet, *a*, suspended in a mercury cup divided into two portions, by being excited by a voltaic battery, is constantly repelled or attracted by the poles of a permanent magnet, *b b*. The principle of this arrangement has been already described at p. 391, *ante*.

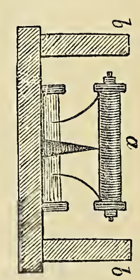


Fig. 225.

Now this instrument illustrates the principles on which nearly all rotating electro-magnetic instruments have been constructed; and the general principle of such arrangements as these, may be described as being that of successive attraction and repulsion of the poles of permanent and electro-magnets, brought about by the reversal of the direction of the voltaic current in the electro-magnets, so that the two forces or effects just

named may be successively called into exercise. It is evident, therefore, that all such instruments depend on the law of magnetic forces—that dissimilar poles attract, and similar poles repel, each other. It is true that in form and general arrangement the early attempts to apply electricity as a motive power produced a great variety, as will be presently illustrated. But the principles of each remained the same.

The following engraving illustrates an electro-magnetic motive machine, constructed on these

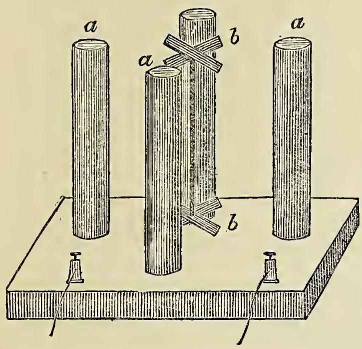


Fig. 226.—Vertical Electro-magnetic Engine.

principles. It consists of a series of vertical permanent magnets, *a a a*, within the poles of which, at top and bottom of the arrangement, horizontal electro-magnets, *b b*, rotate. The method of breaking contact is precisely similar to that already described at p. 391, *ante*, and illustrated by Fig. 212, and also by the engraving preceding the above (Fig. 225). In either case, the electro-magnets being excited by a voltaic battery, are attracted and repelled by, and also attract and repel, the poles of permanent magnets.

In all electro-magnetic machines in which motion is obtained in a tangential arrangement (a term already explained at p. 388, *ante*) of permanent and electro-magnets, there have been numerous forms, according to the ideas of their inventors. The permanent magnets are always stationary ; and the electro-magnets are made to revolve so that their poles may be nearly in contact with those of the former kind. The annexed engraving gives a view, in section, of another kind of machine, and shows the relative position of each set of magnets. The less important parts are omitted, as is also the arrangement, by means of which contact is broken between the electro-magnets and the battery ; for such varies much in form, whilst the principle is the same in nearly every instance.

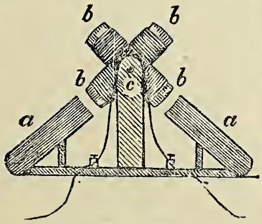


Fig. 227.

In the above figure, *a a* are two permanent and compound horse-shoe magnets, which are fixed on a wooden foot ; *b b b b* are the four terminals, or poles, of as many electro-magnets, made in the usual manner. The wires of the ends of each electro-magnet are attached to a suitable arrangement, by means of which a current of electricity from a few cells of a voltaic battery is conveyed by them. As each pole of the electro-magnets approaches those of the permanent magnet, the current of electricity, producing magnetism in the soft iron, causes a powerful attraction. As the pole passes a little beyond the centre of the permanent magnet, the supply of electricity is cut off, and the soft iron thus returns to its normal state. Of course, the same happens to each electro-magnet as it approaches either of the permanent magnets, and thus a rapid revolution is produced. Very little power is afforded by this arrangement, which may be taken as a type of its class. In some of these machines a permanent magnet is placed so as to be opposite each electro-magnet, as formed during the fourth of a revolution ; and the number of both may be increased to any extent. These may be arranged to revolve on their axis at a speed as great as from 300 to 500 times per minute; but owing to the attractive force diminishing in a rapid ratio as each magnet passes on, the motion of the machine may be stopped by the slightest obstacle applied to the arms of the electro-magnets. When machines of this kind are constructed on the large scale, and used for driving lathes, &c., the speed of the driving-wheel, or that which communicates its motion to the machinery, is diminished below that of the electro-magnets by the interposition of various-sized cog-wheels.

One of the most effective instruments, as a model of this class, that we have seen, was that constructed by Messrs. Watkins and Hill, now Elliot Brothers, of Charing Cross. In general principle, its arrangement is similar to the one just described. It is represented in the following cut, in which E E are electro-magnets, and P permanent ones.

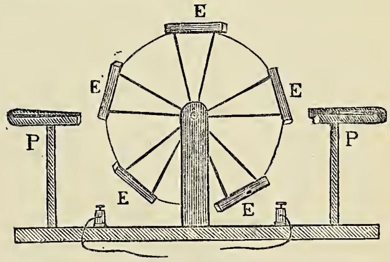


Fig. 228.

In all such arrangements, and, indeed, in every form of electro-magnetic machine, the great difficulty that occurs, apart from the principles of their construction, is that of keeping the surfaces clean at which contact is broken. For small models, mercury cups and amalgamated wires are employed : but such are only worked by means of comparatively weak battery power. When, however, large

batteries, as of forty or fifty cells, of any of the nitric acid forms are employed, then the combustion of the mercury and of the wires would be such as speedily to destroy all contact. Hence, in large machines, of the rotatory and other kinds, wheels are employed, the rim of which is composed of alternations of non-conducting material, such as wood, ivory, &c.; and conducting matter, such as copper, brass, or other metals, the mass and solidity of which are sufficient to prevent their destruction by the heat generated by large batteries, of intensity and quantity which have been above referred to. But even in these improved arrangements, unless platina or gold be employed for the metallic surface, the rapid oxidation caused by combustion in the atmosphere, speedily impairs their efficiency.

It will be unnecessary for us further to describe the various forms that have been given to the rotating electro-magnetic engines which we have seen, from sizes that could be carried in the hand, up to some weighing about a ton. For all purposes of a practical nature, on the large scale, they have, up to the present, proved failures, except where the cost of working has been no object, and the value of having an engine instantly set in motion for light work, has been desired. Lapidaries, watchmakers, jewellers, and other similar trades, may find such a mean of motion exceedingly desirable; for little power, with rapid motion, is what they require.

All form of rotatory machines that have been described or hinted at, have, as a rule, so little resisting power, that they may, when even of the largest size, be stopped either by the finger or the hand applied to the extremity of the rotating electro-magnet. Hence, it will be apparent, that their application must necessarily be limited to such circumstances or requirements as have just been named.

The rare use of a rotatory, and the almost constant use of a reciprocating, or crank form of steam-engine, perhaps led at first to the attempt of employing a crank motion in many proposed forms of the electro-magnetic motive machine; but, as already noticed, with little better effect over the rotatory kind.

This form of machine, like that which we last described, has been the subject of numerous modifications: its type, however, is illustrated in the following engraving. In Fig. 229, the general arrangement will be seen of one side of these machines: *a* is the electro-magnet; *b* is a soft iron keeper, attached to the lever, *c*—this having a fulcrum at *d*. The lever is attached to the crank at *e*, which is again fixed on an axle of the fly-wheel, *g*, at *f*. The other cranks, &c., are not shown, so as to avoid confusion of detail. When a current of electricity passes round the electro-magnet, the attraction induced draws down the keeper, and so, by means of the lever, produces a rotary motion through the crank fixed on the shaft. As one keeper rises, the other one falls, and thus the general action resembles that of a double-cranked, &c., steam-engine. The contact between the electro-magnet and the battery is broken by means of any form of contact-breaker, attached either to the crank or lever. By means of this form of machine, a

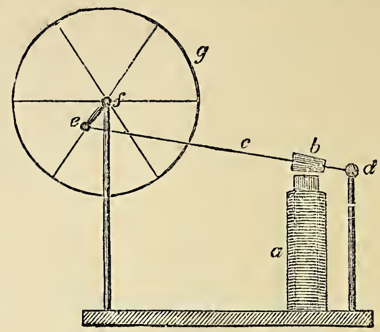


Fig. 229.

greater amount of power is obtained than that produced by those previously explained; but still the result, in an engineering point of view, is comparatively trifling. This need not be a matter of surprise if we consider the conditions that are imposed on the use of the crank in electro-magnetic engines. In the steam-engine the crank is necessarily equal in length to just half that of the cylinder; for when the piston or connecting rod raises it through a space of 90°, only one-half of the semicircle performed by the passage of the piston through the whole length of the cylinder has been described. In other words, the length of the crank is, at all times, equal to one-half of the stroke. Now there is no difficulty whatever, in the construction of a steam-engine, in making any length of cylinder, piston, or connecting rod, and crank. They are simply matters of choice on the part of an engineer. In all cases the whole force of the steam is directly impressed on the surface of the piston to move the crank.

But in the force generated by the electro-magnet, it has already been shown, that the instant the keeper, *b*, leaves the surface of the electro-magnet, *a*, as in the preceding cut, the attractive force of the magnet on it is enormously decreased. The most powerful electro-magnet yet constructed has but a trifling attractive force at a distance of six inches from its surface. Again, as a crank will not work well unless it has a certain length of throw, some arrangement must be made to give this, which is effected in the machine represented in the preceding cut, by using such a form of lever as will permit of the crank.

The lever employed in the machine is one of the third order. This kind of lever is represented in the following cut. The fulcrum, F, in this cut represents *d* in the preceding one. A P corresponds with *b*, and is the power; whilst B W is the equivalent of *e f* in the electro-magnetic machine. (see Fig. 231).

It does not require much mechanical knowledge to find out that such a form of lever is about the worst in which power can be employed for motive purposes. Practically it never is used in any other motive machine: such, for

example, as the water-wheel, windmill, and steam-engine. In all these levers of the first order are employed. For those of our readers unacquainted with the difference of these two forms of levers, it may be desirable that we should enter into a brief explanation.

Lever of the first kind.—In the lever of the first kind the power P (Fig. 230) and the weight W act in the same direction on opposite sides of the fulcrum F. A crowbar by means of which a man easily raises a heavy body, is an instance of a lever of the first kind.

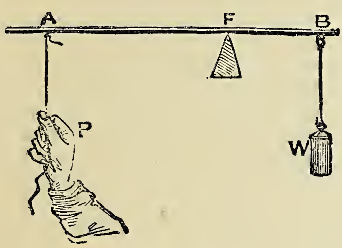


Fig. 230.

If a poker be just inserted within the bars of a fire-place, the least pressure of the hand at the knob end will be sufficient to crush the coal. Now a poker is a lever of the first order; as is also a spade, a "jemmy," a pair of scissors, pincers, etc.

Lever of the third kind.—In the lever of the third kind the power P (Fig. 231) and the weight W act as in the second kind, in opposite

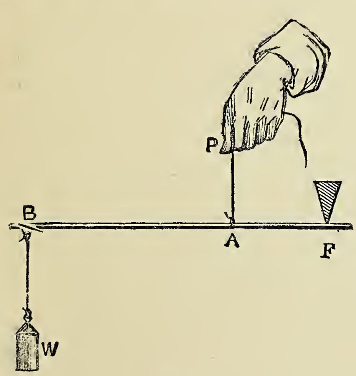


Fig. 231.

directions on the same side of the fulcrum; but in the third species of lever, the power is nearer the fulcrum than the weight.

The following cut represents a reciprocatory or crank-motion engine, as constructed by M. Froment, of Paris. In it the keeper of soft iron rises and falls perpendicularly over the electro-magnet; and by a sufficiently obvious mechanical arrangement, the motion is communicated to a crank overhead, which, in turn, moves a fly-wheel.

Some years ago we saw an excellent form of electro-magnetic motive engine, constructed by Mr. Allan, the celebrated electrician, whose

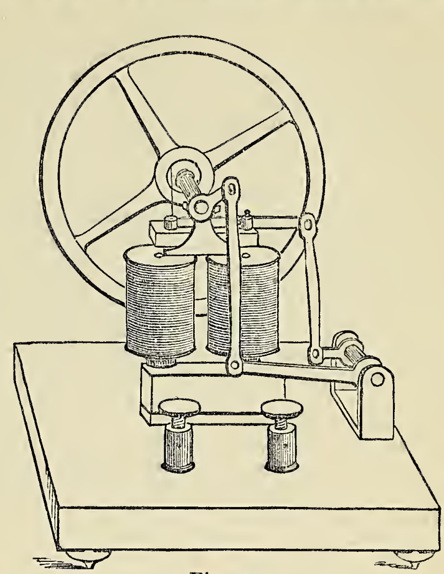


Fig. 232.

name has for many years been prominently connected with electro-telegraphy, and other applications of electricity. He obtained a motion by a series of successive actions by electro-magnets on a crank. A series of electro-magnets, *a*, arranged one above the other, as shown in the annexed engraving, act on circular discs, *b*, of soft iron, one being over each magnet. These discs are perforated with a hole, through which a rod fitted with pins passes; the rod being connected by a connecting rod, *c*, with a crank, *d e f*, over-head. In the machine that we saw, four or five sets of the arrangements were placed side by side, with cranks at various points of revolution; so that whilst one was out of action, another would be commencing; one would be at full action, and so on. In the annexed engraving only one set of crank electro-magnets, &c., is represented.

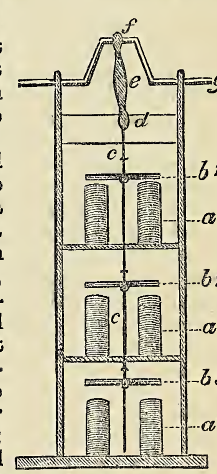


Fig. 233.

On the current of a battery communicating with the electro-magnets, all of which are fitted with suitable contact-breakers, attraction commences, say with the top disc and electro-magnet. This pulls the crank through a short distance by dragging down the pin of the rod running through the disc; then the electro-magnet second and beneath the first is called

into action, and it pulls the rod connected with the crank still further down. The first electro-magnet has already been put out of work, as is also the second so soon as it has performed its office. The third then commences to work. Of course, in each tier of magnets, the same operation is proceeding; and thus, by this ingenious contrivance, Mr. Allan, by successive attractions, is enabled to so act on a crank, that, theoretically, he may use any length of throw he pleases.

But ingenious as the instrument is, it labours under the universal ban of the residual magnetism. The magnets do not instantaneously part with their induced magnetism; and, consequently, whilst some of them are exercising their full attractive power, others are becoming a drag on the machine. On more than one occasion, we have, with a powerful battery in action, seen such a machine come to a dead lock, owing to the opposition of the induced and residual magnetism.

Many other ingenious machines have been proposed; but, as already related, with no practical success; and we shall therefore leave the subject for the present.

ELECTRO-MAGNETIC CLOCKS, Etc.

Amongst one of the earliest attempts to apply electro-magnetism, was that of adapting it as a prime mover to clocks. It will be familiar to all our readers, that the ordinary method of obtaining motion for instruments measuring time, is either to employ gravitative force in the form of a weight, as in the ordinary clock, or the elasticity of a spring. In either case the purpose is to overcome the friction of the works by affording a motive force, the rate of exercise of the latter being regulated either by the pendulum in ordinary clocks, or by means of the balance-wheel, as in the watch, and some forms of clocks.

When the attractive force of magnetism, as developed by electro-magnetic induction, became well known and recognised as a new mode of force, it was proposed to employ it as a motive agent of the ordinary pendulum—a plan illustrated in the following engraving. *a a* repre-

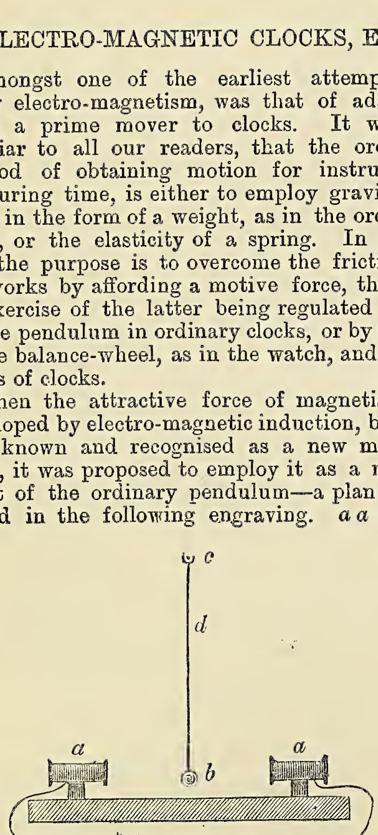


Fig. 234.—Electric Clock.

sent two sets of electro-magnets, fixed horizontally on a board; *b* is a ball of soft iron, suspended by means of a rod from a pivot, *c*. Contrivances of the ordinary kind, but not shown in the cut, are employed to make and break contact with a voltaic cell, by means of which the electro-magnets, *a a*, are excited. The action is thus:—Supposing the ball, *b*, to be oscillating towards one electro-magnet—this is supposed to be in attractive action; but on the ball nearly reaching that electro-magnet, the current acting on it is cut off, and, consequently, the ball, or bob of the pendulum, falls away from it, in obedience to the laws of gravitation; but its impetus carries it beyond the vertical line, *d*, and, consequently, it is attracted by the other electro-magnet, which gets into action on the other ceasing to be in that condition: consequently, so long as the voltaic current is passing, to excite the electro-magnets, the motion of the pendulum should be maintained. The clock-work of the time-keeper, in such arrangement, differs in nowise from the ordinary clock; for it will be apparent, that the only difference between the common and electric clock, in such circumstances, would be, that, in the latter case, magnetic attraction is substituted for that of gravitation.

Amongst the earliest inventors of clocks worked by the voltaic current, were Mr. Bain and the late Sir Charles Wheatstone. An able writer has remarked—"Disputes respecting priority of invention are always painful, and seldom satisfactory. With respect to the subject before us, the question at issue is, whether Professor Wheatstone or Mr. Bain is the inventor of the electric telegraph, and, also, of the electro-magnetic clock? Setting aside the legal rights which both parties sought under the banner of the patent laws, the moral right, which is of a far higher order, unquestionably belongs to the working mechanic, as Professor Wheatstone disparagingly designated the young stranger from Caithness. * * * * But we must take exception to the claims of both parties to the merit of being first discoverers that an electric current can be transmitted from one distant point to another, through the ground or through water. This discovery belongs to Professor Steinheil, of Munich; and is detailed in his paper upon *Telegraphic Communication by Means of Galvanism*—a translation of which, by Julian Guggsworth, may be found in Sturgeon's *Annals of Electricity*, vol. iii., pp. 439 and 509; published in March and April, 1839. * * * * Alluding to the number of wires required in the different electric telegraphs proposed, he says—'Ampère required more than sixty wires; whereas thirty were sufficient for Sommering. Wheatstone and Cooke reduced their number to five; Gauss, and, probably, in imitation of him, Schilling, as likewise Morse, in New York, made use of but a single wire, running to this distant station and back. One might imagine that this arrangement could not be further simplified. Such, however, is by no means the case. I have found that even half of this length of wire may be dispensed with; and that, with certain precautions, its place is supplied by the ground itself. We know, in theory, that the conducting powers of the ground

and of water are very small compared with metals, especially copper. It seems, however, to have been previously overlooked, that we have it within our reach to make a perfectly good conductor out of water, or any other of the so-called semi-conductors. All that is required is, that the surface which its section presents should be as much greater than that of the metal as its conducting power is less. In that case the resistance offered by the semi-conductor will equal that of the perfect conductor; and as we can make conductors of the ground of any size we please, simply by adapting, to the ends of the wires, plates presenting a sufficient surface of contact, it is evident that we can diminish the resistance offered by the ground or by water to any extent we may choose. We can, indeed, so reduce this resistance as to make it quite insensible, when compared to that offered by the metallic circuit; so that not only is half the wire spared, but even the resistance that such a circuit would present is diminished by one-half. This fact, the importance of which, in the erection of galvanic telegraphs, speaks for itself, furnishes us with another additional feature in which galvanism resembles electricity. The experiments of Winkler, at Leipzic, have already shown us that, with frictional electricity, the ground may replace a portion of the discharging wire: the same is now known to hold good with respect to galvanic currents.'"

For the present, much of the preceding quotation will seem to have little bearing on the subject in question; but, as we proceed, that view will become gradually modified, and, at last, it will be seen that the method of transmitting electricity by one wire, with a return current through the earth, is an essential feature in one of the chief modes of using voltaic currents for the regulation of time from one standard, as it is in every modern system of telegraphy.

We have purposely abstained, and shall continue to do so, from entering into any discussion in respect to the merits of inventors, in regard to priority of discovery. Were we to attempt to enter such an arena of strife, it is with much regret that we have to state, our volume would be too small to even briefly discuss such questions. The readers of Faraday's *Experimental Researches*, will find that, on several occasions, Faraday had to make out a distinct claim to originality of discovery, that was unjustly laid either to the charge of plagiarism on his part, or credited to others. Even recently it has been attempted to show that Sir Isaac Newton robbed Pascal, and so got credit for discoveries, said, but evidently falsely, to have been made by the latter. In our own days many such strifes have arisen; and we cannot pass, without brief notice, the acrimonious dispute that has been carried on between Mr. Cooke and Sir C. Wheatstone, as to their respective rights in electro-magnetic and telegraphic discoveries or inventions. In connection with this latter question (which will now be dismissed), many of our readers may take an interest in the following statement, extracted from that able periodical, the *Saturday Review* (Nov., 1866). A writer therein observes, as to "Who invented the Electric Telegraph?"—

"The great services of Mr. Wheatstone are generally acknowledged; and there is no reason to question the claims of Mr. Cooke: but as both of the parties to the Brunel award have deservedly acquired both fame and profit by their telegraphic exploits, it is but just that the modest merit of Mr. Ronalds, who happily still survives, should not be forgotten. In the preface to his pamphlet of 1823, Mr. Ronalds 'takes leave of the science' which was destined, in his own lifetime, to attract the attention and wonder of the world. Without repining, and without resentment, he mentions the official answer which had been returned to his proposals for establishing an electrical telegraph; and he merely records his exposition of the method by 'which that most extraordinary fluid or agency, electricity, may actually be employed for a more practically useful purpose than the gratification of the philosopher's inquisitive research, the schoolboy's idle amusement, or the physician's tool; that it may be compelled to travel as many hundred miles beneath our feet as the subterranean ghost which nightly haunts our metropolis, our provincial towns, and even our high roads.' The date of the discovery is curiously verified by frequent reference to the distance between Downing Street and the Pavilion at Brighton. George IV. was still king, though Mr. Ronalds' invention was completed during the regency, and, consequently, Osborne and Balmoral were still far off in the future. It was then still believed that ready communication between the reigning sovereign and the cabinet was indispensable to the conduct of the government. The explanation of the process in Mr. Ronalds' pamphlet is short and simple; and after Mr. Wheatstone's testimony to the priority of Mr. Ronalds' claim, it is unnecessary to inquire into the genuineness of the discovery. The inventor has since received a small pension from the crown; but, except for the recent discussion, he might have been unintentionally defrauded of his well-earned fame."

Leaving, then, such questions of dispute, that neither advance science nor do credit to the antagonists, we notice briefly the early history of the application of electro-magnetism to clock-work, in an extract from *Engineering*:—

"Clocks in which a voltaic current is the motive power have been invented by several electricians, amongst the earliest of whom may be mentioned Bain, Froment, Paul Garnier, Henley, and Shepherd. It does not appear, however, that the advantages gained by using a voltaic battery as the motive power, instead of a spring, to move the hands of a single clock, are sufficient to cause the ordinary clock to be superseded by these instruments; for although some have been invented twenty-five years, they appear more scarce than ever. The advantage of not having to wind up the clock once a week, is probably counterbalanced by the simplicity of the operation of winding, as compared with the attention required to keep the electro-motive

force of a voltaic battery constant. However this may be, electric clocks—that is, clocks *worked* entirely by electricity—have not come into general use. To cause several clocks, however, in the same building or town, or even separated still more widely, to keep exactly the same time, is, it is evident, a very important desideratum. Even with the best and most expensively-made clocks, to make a dozen keep time to a second—nay, even a minute—for a month together, would require the constant attention of some clock-maker's assistant. We are not, of course, speaking of chronometers, although even these all have their 'rates,' and, consequently, are not available for instant reference.

"To distribute accurately the time of a single good clock or regulator to any number of cheap clocks, or rather dials, by electricity, is manifestly a fair problem for electricians.

"Wheatstone, in 1840, proposed to move the hands of several clock-dials by means of a propelment attached to the armature of an electro-magnet, the mechanism to be similar to that of his 'step by step' alphabetical telegraph instrument, patented January 21st, 1840, the circuit being broken, and completed by a make-and-break contact arrangement in a regular clock. The *Bulletin* of the Brussels Academy states that Wheatstone had 'applied' this principle to clocks before the 8th of October, 1840.

"Bain patents a similar method of propelling the hands of distant clocks, the patent being dated January 11, 1841.

"Froment and Garnier afterwards constructed a clock which moved the hands of eighteen dials.

"The history of the many modifications that have followed, up to the present time, would fill a volume. It appears, however, as far as we can trace, that, in all the arrangements for *propelment* of distant clocks, up to that we are about to describe, the propelment has been caused by the excitation of one or two electro-magnets acting on a soft iron armature attached to the crutch carrying the pallets. When a single electro-magnet was used, therefore, gravity, or a spring, was the antagonistic force to that produced by the electro-magnet. When two electro-magnets were used, two separate circuits were necessary, and a current sent first through one electro-magnet moved the crutch in one direction, and a current through the other moved it back in the reverse direction. This necessitated two wires."

The first electric clock that was exhibited in action publicly, that we are aware of, was one constructed by Mr. Bain; and, if our memory does not fail us, it was shown in the Polytechnic Institution, Regent Street, London. "In his first arrangement, Mr. Bain proposed to work a number of clocks simultaneously, the clocks being all included in the same voltaic current. The pendulum of the prime mover carried, near its upper end, a light brass spring, that acted upon a plate of ivory fixed to the frame of the clock, and having a slip of brass inserted in it, in connection with the positive pole of the battery. By this contrivance, every vibration of the pendulum causing the spring upon it to pass over the slip of brass in the ivory plate, completed the circuit, the pendulum itself being in constant connection with the negative pole of the battery." This arrangement was worked with an ordinary voltaic battery; but, subsequently, Mr. Bain availed himself of the earth as a source of electricity, so as to have a constant current for a lengthened period, without the necessity of re-charging with acid or saline solutions, as is necessary in all voltaic cells. For this purpose a plate of copper and zinc were buried, facing each other, in moist earth, each plate having several feet surface, so that they might supply sufficient quantity of electricity, the large size of the plates compensating for the weak chemical action of the saline substances in the moist earth on the zinc. Such a battery may be kept months in action. Of course, a wire extended from each of the plates to the electro-magnets, between which the bob of the pendulum vibrated, that so gave motion to the works of the clock, magnetism taking the place of gravitation as a motive power.

Suppose a primary clock to be thus set in motion by the magnetism produced by voltaic current induction, it is evident that, by a very simple mechanical contrivance, such as a magnet, and a keeper that will vibrate opposite the poles of the magnet, any number of other clocks might be made to work synchronously with the primary one; for as the pendulum of this vibrates, it not only would make and break contact of the current with its own electro-magnets, but with that of any other number of clocks connected with it by means of conducting wires.

"By this arrangement it was necessary to increase the power of the electric current in the ratio of the number of clocks that had to be kept in motion. To avoid this practical difficulty, Mr. Bain proposed to work the clocks, when the number was great—not simultaneously, but in rotation. For this purpose a ratchet-wheel was placed on the arbor of the *minute hand* [the second's movement having been previously adopted], and it was moved once a minute, instead of once a second, in the following manner:—Upon the face of the regulating clock was fixed an ivory circle, with slips or studs of metal inserted into it, flush with its surface, and corresponding in number with the number of clocks to be worked. In the centre of this circle was placed the arbor of the second's hand of the clock, upon which was fixed a slight metal spring, with its free end in contact with the ivory circle. The conducting wire in connection with the positive pole of the battery, was in connection with the frame-work of the clock; every time, therefore, that the second's hand passed over a metal stud in the ivory circle, an electric circuit was completed, and a current transmitted to the clock, or groups of clocks, in connection with that stud; and as the second's hand passed over every portion of the circle once in each minute, the whole number of clocks thus connected with the regulating clock, moved for-

ward one degree during such a revolution; that is, every minute of time [of course, on the face of the clock, this would amount to $\frac{1}{60}$th of a circle, or six degrees of space in the circular face of the clock]. By this arrangement a large amount of electric power was saved, since the current had only to act on a single clock, or a group of clocks, at each instant."

On this method of communicating time from place to place being brought out, we adapted two clocks in different parts of the house, after the plan proposed by Mr. Bain, and a tolerable amount of success resulted. But despite attempts by many able men of scientific and mechanical experience, the adaptation of electricity for clock-motion, and the communication of "time" from a standard to a distant or many distant clocks, made very slow progress. One of the many instances of this public use was that erected in the Strand, near Trafalgar Square, the object of which was to show mean Greenwich time. The minute-hand, as in the arrangement just described, moved through the space of one minute's indication at a leap, so that, in any possible case, a watch or clock could be compared with it only by minutes instead of by seconds. Now the majority of clocks on church steeples, and in public thoroughfares in London, are rarely, on an average, a minute wrong. If any one living within a radius of two or three miles from St. Paul's church, will take the trouble to mount to the roof of his house at eleven or twelve o'clock at night, when the noise or hum of the metropolis is hushed, and note the difference between the time when the first clock strikes and the last finishes striking—out of the scores of sounds he will hear, there will not be more than a minute or a minute and a-half's difference between the first and last sound. Hence, such a minute clock as we have been describing is of little or no use. But the Strand clock had some peculiarities or whims that rendered it worse than useless. Whether from defective construction, or occasional obstruction of the current working it, the clock would occasionally stop, leading to great confusion of watches, clocks, and the tempers of certain perverse individuals, who, taking it as the standard, stood on the correctness of their time-keepers. At last its vagaries became such a nuisance, that, from sheer shame, its owners removed it, and thus came the end of the last public electric clock in the metropolis.

We cannot spare space necessary to describe the endless variety of schemes that have been invented to communicate time from a standard or regulating clock to others. In 1855, an automatic arrangement was fitted up at the central station, Lothbury, which sent Greenwich time to ten or twelve of the principal stations. This consisted of a circular board, around which the provincial line-wires terminated on horizontal flat springs radiating towards the centre. The ends of these springs, when in their normal state, were over, but raised from, a series of contact pieces, connected with one of the poles of a series of batteries, the other poles being in the earth. In the centre of the board was a vertical rod, on which a heavy horizontal disc could be slid freely up and down, and which, when allowed to fall, pressed all the springs into contact with the batteries, the contact-pieces thus sending currents into all the line-wires.

When raised, the disc could be held up clear of all the springs, by means of a trigger attached to the armature of an electro-magnet. The coil of the electro-magnet was in circuit with the Greenwich Observatory line-wire; then the Greenwich clock made contact, and, consequently, sent a current through the electro-magnet, the trigger was released, and the disc, falling, placed all the springs in contact with their batteries, thus sending a current on each of the lines to the distant stations. The signal produced by this was, of course, compared with the office clocks, which were thus set right to Greenwich time once in every twenty-four hours.

Mr. French, in Leadenhall Street, and afterwards Mr. Bennett, in Cheapside, erected time-balls, which were released by a current from Lothbury (the head office of the Electric Telegraph Company); these arrangements being carried out by Mr. Latimer Clark. Later, the General Post-Office, in St. Martin's-le-Grand, and the Lombard Street branch, were "served with time" from the cellars of Lothbury, but Greenwich is now the source. The great clock at Westminster is now supplied regularly every hour; and a gun is fired, at one o'clock, at Newcastle, Edinburgh, etc. Private individuals are also supplied with "time."

The automatic arrangement first employed is that perfected by Mr. C. F. Varley, and has been termed the *Chronopher*, or *Chronofer*. The following account of it is condensed from Mr. Varley's description of the arrangements:—

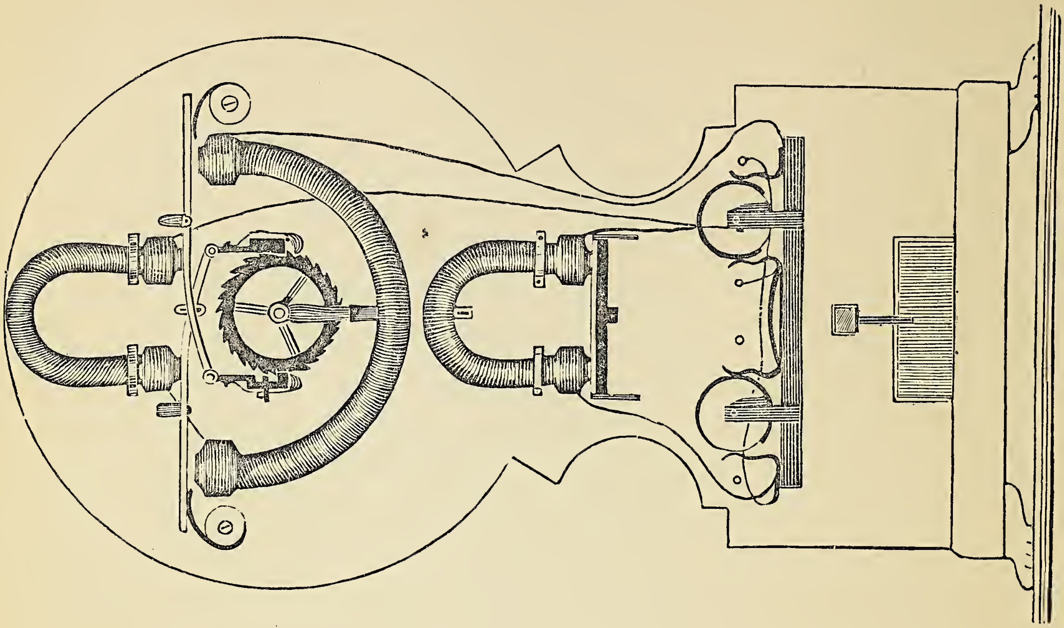
The Chronopher—a term derived from χρονος *time;* and Φερω, *I bear*—of which the design and arrangement are represented in the next page—consists of the following apparatus:—

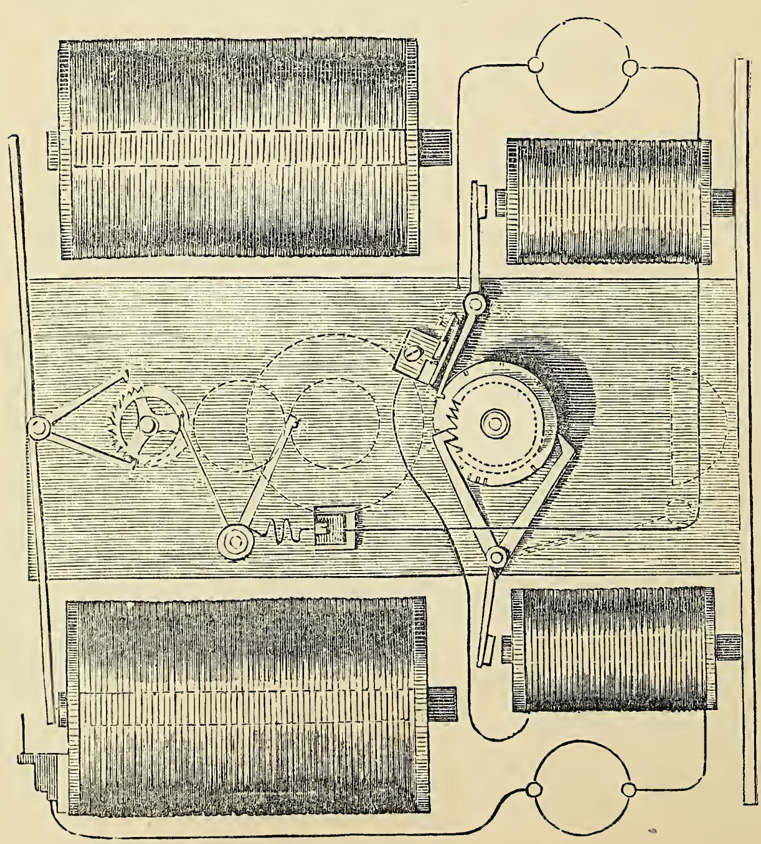
1. A clock, to control the whole of the changes and connections.
2. Various sets of voltaic batteries, to supply the current which gives the signals to the various stations.
3. A large commutator, or switch (to use a railway phrase), for connecting the lines to the chronopher when time is to be transmitted.
4. Two relays,* which give the actual time-signals to the different stations.
5. Two electro-magnetic switches, the use of which will be hereafter described.
6. Two galvanometers, to show, by the deflection of the needles, the passage of the current.

These various parts of the apparatus will now be described in detail.

The clock employed in connection with the chronopher, is a well-constructed time-keeper, furnished with a double means of adjustment. The pendulum consists of a rod of pine wood, carrying a cylindrical bob of zinc, supported by a nut on a fine thread-screw. There is an ordinary delicate adjustment; but, for further

* The nature of a relay electro-magnet will be subsequently explained.





and more delicate regulation, the following arrangement is made:—A long spiral spring is attached to the bottom of the pendulum, and suspended, by means of a silk thread, to a rod, which runs through the clock-case to about a foot below the point of suspension of the pendulum itself.

The circumference of the rod is exactly half an inch, and it is terminated outside the case by a milled nut, furnished with an index or pointer in front of a circular disc, divided into 100 equal parts. It is, therefore, evident, that when the rod is turned, the silk thread will be either wound or unwound, and the spiral spring tightened or loosened, each of the divisions on the disc being equal to $\frac{1}{200}$th of an inch of the silk thread. The clock, by the first adjustment, is made to go slightly slow—say at the rate of ten seconds per day: the spiral spring being tightened, has a tendency to accelerate the pendulum, and this brings the clock into exact and perfect time. It has been found, by experiment, that an alteration of $7\frac{1}{2}$ divisions, either way, will alter the clock at a rate of one second in twenty-four hours.

The clock, in addition to the ordinary wheels common to all clocks of the same kind, has a wheel revolving once in twenty-four hours. On the same axle as the twenty-four-hour wheel, and revolving with it, are two solid discs or wheels of ebonite: the front ebonite wheel has two notches cut in it, corresponding to 10 A.M. and 1 P.M.; the back ebonite wheel has one notch only, that corresponds to 10 A.M. These ebonite wheels will afterwards be called, respectively, the *front* and *back twenty-four-hour wheels.* On the same axle as the hour-wheel, and revolving with it, are two similar, but somewhat smaller, ebonite discs. In each of these discs is inlaid a small contact-piece of platinum, which is in metallic connection with the frame of the clock through the axle. These ebonite discs will hereafter be called, respectively, the *front and back hour-wheels.* In the back hour-wheel is fixed a pin, the use of which will be explained further on. On the same axle as the wheel which carries the second's hand, is fixed a small metallic projecting piece, about half an inch long, and tipped with gold; this piece is also in connection with the frame of the clock through the axle.

Below the second's hand is fixed a double metallic lever, shaped like the letter V; the lower end of the lever is made sloping, and hangs down between the hour-wheels; the upper end carries a small gold spring, which, in the normal state of the clock, hangs about one inch below the axle of the second's hand. This lever will hereafter be called the *second's lever;* it is so arranged, that when the pin in the back hour-wheel touches its lower end, the gold spring is so raised that the next revolution of the second's hand brings the gold-tipped piece into contact with it. Above the twenty-four-hour wheel, but insulated from each other, and from the clock, are two other V-shaped metallic levers. The lower ends of these levers rest on the edges of the twenty-four-hour wheels, and the upper ends, in the normal position, rest about one-eighth of an inch above the hour-wheels. The front, or lower, of these levers, which rests on the front twenty-four-hour wheel, is used in connection with the Newcastle time arrangement; it will, therefore, hereafter be called the "Newcastle lever." The other lever is used in connection with the electro-magnet in the commutator; it will, therefore, be called hereafter the "commutator lever."

The Galvanic Batteries.—Of these there are five separate sets; and though some of these consist of a number of troughs and elements, each set will be hereafter mentioned as a "battery," distinguished by numbers from 1 to 5.

These sets of batteries are also shown in the drawing as single batteries, for the sake of simplicity.

Battery No. 1.—The copper pole of this battery is connected to the frame of the clock, and the zinc pole has a double connection, one going through the coils of the electro-magnetic switch which brings the relay into operation, and thence to the "second's lever" in the clock; the other through the coils of the electro-magnet which discharges the mechanism of the commutator, and thence to the "commutator lever" of the clock. It will thus be seen that when the upper end of the commutator lever is allowed to come into contact with the platinum piece in the back hour-wheel, a current flows through the coils of the electro-magnet to which it is connected, attracting the armature (it being remembered that the platinum piece is in metallic connection with the clock frame). In the same way the electro-magnetic switch is brought into action whenever the gold-tipped piece on the second's hand axle comes into contact with the gold spring of the second's lever. The use of one battery to perform these two services never causes any inconvenience, because the contacts are never made at the same time, and one at least of the two different circuits is always disconnected.

Battery No. 2.—The copper pole of this battery is joined to the clock-frame; the zinc pole to a wire which traverses the coils of the Newcastle electro-magnetic switch, and thence to the "Newcastle lever" in the clock. The platinum piece in the "front hour-wheel" being in metallic connection with the clock-frame, it follows, that whenever the upper end of the "Newcastle lever" comes into contact with it, the Newcastle switch is brought into operation, joining the line to the relay, as will be explained hereafter.

Battery No. 3.—This is a powerful battery, the copper pole of which being connected with the earth, the zinc pole is joined to the back stop of the provincial relay. This battery supplies a zinc current to all the provincial lines on which "time" is sent from the moment they are disconnected from their ordinary instruments until the positive or copper current which gives the actual time-signal is sent; on the cessation of the time-current, which lasts a second and a-half, the zinc current again occupies the lines until they are once more joined to their instruments. The object of this negative current

is to avoid the effects of stray currents from other wires, or "contacts," as they are termed, and other interruptions, by which a false signal might be given. It also serves to make the "time-signal" more easily distinguished, as by this arrangement it is the reversal of a current, instead of a current sent into a line previously unoccupied.

Battery No. 4.—This is a still more powerful battery, employed to give the hourly time-signals to the various local stations in London. The zinc pole is to earth, and the copper pole is joined to the front stop of the local relay. In connection with this battery is a zinc and carbon battery, charged with sulphuric acid and water, which is joined to the other in the same fashion as the gas battery in No. 5; but with carbon to copper, and zinc to zinc. The power of the principal battery overcomes the force of the carbon and zinc battery, causing zinc to be returned on to the amalgamated zinc plate, and oxygen to be evolved at the surface of the carbon. At the moment of contact, the power which is thus gradually accumulated discharges itself, almost with a force of a Grove's battery. This zinc, carbon, and acid battery, having a very small resistance compared to that of the constant Daniell's battery, produces a current of very large quantity, and requires no attention whatever.

Battery No. 5.—This is a powerful battery, similar to No. 4; its zinc is joined to earth, and the copper to the front stop of the provincial relay. It is employed to send the positive "time-signal" current to the provincial station at 10 A.M.; and to Newcastle at 10 A.M. and 1 P.M. [To which we add, that communication is simultaneously made with Edinburgh; at which city, by an ingenious arrangement, a cannon is fired at 1 P.M., simultaneously with the fall of a time-ball]. Attached to this battery, as shown in the engraving, is a gas battery, consisting of a number of carbon plates, arranged in a trough, which is charged with dilute sulphuric acid and water. The carbon plates are carefully insulated from each other. The constant passage of the electric current through this battery decomposes the water, when hydrogen is thrown off on one side of the carbon plates, and oxygen on the other. These gases are condensed in the pores of the carbon plates. When the time-current is sent from the battery, the accumulation of the power is such, that a current is obtained almost equal to that from a Grove's battery.*

The Commutator.—This is an apparatus by which the different provincial lines are disconnected from the ordinary telegraph instruments, and joined to the relay, which transmits the time-currents through them. The provincial wires are brought to a series of tumblers, which, in their normal condition, rest on stops in communication with the respective instruments. In front of these tumblers is an eccentric barrel, set in motion by an independent and slow train of clock-work provided with a balance escapement. The barrel is in permanent connection with the bar of the relay, through an extra tumbler which presses on the barrel in front. The clock-work is stopped by a catch, which falls into a notch in the wheel that revolves with the barrel. This catch is at the end of the lever of an electro-magnet. When the electro-magnet is brought into action it unlocks the wheels, and the clock-work starts of itself; the contact is continued long enough for the notch to get well clear of the catch, and then ceases. The revolution of the barrel takes place in three minutes; and during this time the lines are disconnected from their instruments; connected to the relay for about a minute before and after the time is sent; and on the completion of the revolution, the clock-work is again locked, and the lines again connected to the instruments.

The Relays.—The two relays used in connection with the chronopher, have hitherto been mentioned as the *provincial* and *local* relays; the former being to the left hand, and the latter to the right in the engraving. These relays are similar to those in use on the lines of old Electric Telegraph Company. They are known as Varley's horizontal relays, and are constructed as follows:—A bar of soft iron, mounted on a centre pivot, is free to make a slight oscillation inside two coils of wire. Outside, and at the ends of these coils, are fixed two permanent magnets. The bar will rest at one side or the other, as it is placed nearer or further from either pole of the magnets. When the current is passed through the coils in one direction, the bar is converted into an electro-magnet, and is attracted by the north pole at one end, and repelled by the south pole at the other end. A current in the reverse direction exactly reverses the motion. The bar is in this case placed a little out of the centre, and is always attracted to one side, except when a current is passed through the coils. One end of the bar oscillates between two screws tipped with platinum; at this point the bar is furnished with spring contacts, so that a jar will not interrupt the connection.

In the ordinary relays a contact is only required at one side, the back screw being tipped with glass or agate; in these relays, however, contact is made at both sides.

The principal advantages of these relays are—

I. There is no spring adjustment whatever.

II. When once adjusted they will work for a very long time without attention.

III. The bar, having no magnetism of its own, can never be demagnetised by a flash of lightning, &c.

The Greenwich current, when the relays are in circuit, passes through the coils of the provincial relay, and then through those of the local, going on at 10 A.M. to earth direct, and at all other times to Westminster. In the provincial relay the bar is connected to the barrel of the commutator, and the Newcastle switch and the two stops to batteries Nos. 3 and 5 respectively. In the local relay the front stop is joined to battery No. 4, and the back stop to earth. The bar has three connections, into which the

* See account of Grove's gas battery, at p. 255, *ante*.

current forks, or divides, viz.: *viâ* B D F and H to earth, *viâ* A (at 10 A.M.) C E G and I to earth, and (at 10 A.M. only) to J K L and M, *viâ* the tumbler of the commutator. The earth connection in the local relay is to prevent any stray current which may arrive on any of the forks or branches from flowing into the others.

The Switches.—One of these switches is in the same case as the commutator; the other is a separate piece. The object of the first is to cut the relays out of circuit at all times, except for a few seconds before and after each hour. This arrangement reduces the chances of a false signal to a minimum, and prevents the clock-setting currents which pass between the Observatory and the post-offices during the forenoon from ringing the bells connected with the chronopher.

From the point where the Greenwich wire enters the first relay, a wire is brought to the pillar of the switch. From the point where the same wire leaves the other relay, a similar wire is brought to the lever of the switch. When all is at rest, the lever and pillar are in metallic connection; consequently, any current arriving chooses the route through the switch instead of that through the relays, in consequence of the greater resistance of the latter, and no effect is produced in the chronopher. The lever of the switch is prolonged beyond the pillar, and its end, when at rest, presses on a spring connected to the Westminster clock-wire, so that the Greenwich current passes direct to Westminster without action on the chronopher. But the switch is moved by a current sent by the clock at nine seconds before each hour; the lever allows the Westminster and Greenwich wires to break contact, and connects the Westminster wire to that terminal of the relay from which the time-currents branch off, so that Westminster is now in the position to receive, in common with the other currents, the relay current instead of the direct current. At the same time the lever puts the Greenwich wire, after it has passed through the relays, to E.

The effect of this arrangement, therefore, is, that at 10 A.M., the Greenwich line being put to earth, all chances of failure in the numerous clocks, connections, &c., and street wire between the central station and Westminster, are avoided; the Westminster wire, being joined to the local relays, still, however, receives a "time-current," as at other times. The great importance of the 10 A.M. current renders this precaution very necessary. In the principal instrument-room is a loud-sounding bell, marked A in the plan, which strikes by a current from the local relay. This bell is only required to strike once a day—viz., at 10 A.M.; and in order that it may be silent at all other times, the following arrangement is made:—The wire which comes from the local relay to the bells, C E G, and I (*vide* plan), is brought to a terminal in connection with the pillar, limiting the upward play of the magnet lever which starts the eccentric barrel; here it has the choice of two routes, either through the magnet lever direct to C, or through the bell, A. When all is at rest, these two routes are both connected, and the current, of course, passes through that having the least resistance, and the bell, A, remains silent. At 10 A.M., however, the lever being depressed, the short circuit is broken, and the current, consequently, passes through and strikes the bell, A.

The other switch is used in connection with the Newcastle time arrangement; for as Newcastle requires "time" twice a day, this line cannot be attached to the commutator. The Newcastle line-wire is connected to the lever, the ordinary instrument to the front pillar, and the back pillar to the bar of the provincial relay. It is, therefore, evident that, when all is at rest, the line-wire is joined to the instrument; when the lever is depressed, the line is disconnected from the instrument, and joined to the relay.

The Galvanometers.—The first galvanometer is inserted in the Greenwich wire before it reaches the relays. It serves to indicate the passage of the current *in* from Greenwich. The other galvanometer is inserted between the provincial relay and the commutator, or Newcastle switch. It shows the passage *out* of the current to the provincial stations.

Manner of Action.—The gradual revolution of the twenty-four-hour wheels brings the two 10 A.M. notches under the ends of the levers, and about twenty minutes to 10 they fall into the notches, allowing their upper ends to rest on the hour-wheels. At 9h. 58m. 20s. the platinum piece in the back hour-wheel comes in contact with the commutator lever, a current flows from battery No. 1 through the coils of the starting magnet, and, depressing the lever, allows the clock-work to start; the barrel then commences to revolve. This contact is only continued about twenty seconds, so as to allow the wheel to well clear the catch. At 9h. 59m. 30s. the platinum piece in the hour-wheel comes into contact with the Newcastle lever, a current flows from battery No. 2 through the Newcastle switch, which disconnects the Newcastle line from the instrument, and joins it to the relay. About twenty seconds after the barrel has begun to revolve, the lines are connected through it with the bar of the relay, which, being at rest, a zinc current from battery No. 3 flows into them. This zinc current flows into the Newcastle line immediately the switch is acted upon. About twenty seconds before 10, and every other hour, the insulated pin in the back hour-wheel lifts the second's lever up, and at about nine seconds to 10 the gold-tipped piece commences to make a rubbing contact with the gold spring, sending a current through the coils of a relay switch, which puts the relays into circuit.

The contact at the gold spring is, necessarily, a very delicate one; and, it was found, did not give a perfectly continuous contact, from the tendency of the gold spring to vibrate, producing a series of short disconnections. This difficulty is obviated by keeping the spring wet with chronometer oil. All being now ready for the receipt of the current, on its arrival from Greenwich it passes through the two relays, and thence to earth. This current lasts one second

and a-half. The provincial relay, being acted upon, sends a current through all the provincial lines from battery No. 5. The local relay, in like manner, sends a current through the local lines from battery No. 4. About nine seconds after 10, the contact ceases at the gold spring, releasing the relay switch, and again cutting out the relays. At thirty seconds after 10, the Newcastle contact ceases, and the line is again joined to its instrument. A 10 h. 1 m. 20 s., the barrel of the commutator having completed its revolution, the catch falls and locks it, the lines being once more joined up as usual. At 1 P.M. the same operation takes place, as far as Newcastle is concerned, there being a second notch in the front twenty-four-hour wheel, which allows the Newcastle lever to complete contact. The commutator does not, however, act except at 10 A.M.

The local relay sends a current *every hour* to the local stations; and an arrangement can be made to send time to any single station in connection with the chronopher, at any hour of the day when necessary. It will be evident, from the foregoing description, that the clock must never be allowed to be more than nine seconds slow or fast. As a matter of fact, it is never anything like so much out. All the points of contact in connection with the chronopher are in platinum, in order to ensure perfect electrical communication.

No one who has carefully perused this account of the chronopher, or the method now adopted for regulating time, according to the Greenwich standard, throughout our islands, at least in all places where such an object can be of importance, can fail to experience delight at the conquest which the intelligence of man has made over the powers of nature. Half a century ago such results as we have described were not only unthought of, but would have been considered, in any person imagining their possibility, as an evidence of insanity. As Dr. Lardner well remarks—"No authority, however exalted—no attainments, however profound—no reputation, however respected—could have saved the individual rash enough to have given utterance to such predictions some fifty years ago, from being regarded as labouring under intellectual derangement. Yet all these things have not only come to pass, but the contemplation of many of them [the Doctor refers also to gas illumination, photography, &c., &c.] has become so interwoven with our habits, that familiarity has blunted the edge of wonder.

"Compared with all such realities, the illusions of Oriental romance grow pale; fact stands higher than fiction in the scale of the marvellous; the feats of Aladdin are tame and dull; and the spirit of the lamp yields precedence to the spirits which preside over the battery and the boiler.

"Of all the physical agents discovered by modern scientific research, the most fertile in its subserviency to the arts of life, is incontestably electricity; and of all the applications of this subtle agent, that which is transcendently the most admirable in its effects, the most astonishing in its results, and the most important in its influence upon the social relations of mankind, and upon the spread of civilisation, and the diffusion of knowledge, is the electric telegraph. No force of habit, however long continued—no degree of familiarity can efface the sense of wonder which the effects of this marvellous application of science excites."

There are two terms that have been used in the preceding pages—"pole to earth," and "relay"—that may be here more fully explained and illustrated.

At a previous page, it was stated that the earth might be made a conductor for a current of electricity, provided another and metallic conductor, carefully insulated from the earth, were also used.

The following engraving illustrates the mode in which the earth is thus employed:—

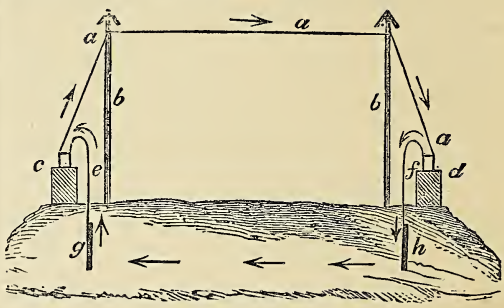


Fig. 235.

In the above engraving, *a a a* represent the conducting wire suspended on the poles, *b b*; *c* and *d* are two telegraph instruments, each of which is connected with the wire, *a*; *e* and *f* are wires which lead respectively from the instruments *c* and *d*; and at the ends of each of these wires, plates of metal, *g* and *h*, are affixed, which are buried at some distance beneath the surface of the ground, in moist earth. Now, supposing a current is passed from the station, *c*, to a distant one, *d*—its course will be by the wire *a a a*, suspended on the poles; proceeding from *c*, until it reaches *d*, and thence leaving the instrument by the wire, *f*, it passes into the earth by the plate, *h*: from this it then returns in the direction of the arrows, until it arrives at the plate, *g*; by means of which it reaches the first station again by the wire, *e*, into the instrument, *c*. A continuous circuit is thus established between the two, or, indeed, any number of stations; and, as we before remarked, it answers just as well, and better than if a second conducting wire were employed.

Our readers will at once perceive the necessity which exists for maintaining a complete insulation of the wire from the earth; and in this is found one of the difficulties of telegraphy. It is almost impossible to keep the wires and poles completely dry during wet weather, although the glass or porcelain-holders intervene. Now, moisture is a conductor of electricity; and, as such, a portion of the current is often diverted from the wire towards the earth, in wet weather,

by means of the wet poles. This circumstance is one, therefore, which interferes both with the speed of transmission and the distinct indication of a message, when rain, fog, or dew are prevalent. This, however, will be more particularly dealt with when we enter on the subject of the electric telegraph.

Relay instruments, in respect to their construction, have already been in part described. Primarily, their object is to call, by means of a first current through them, another into action, in cases where the first current would have been too weak for a long distance. A form of relay instrument is represented in the above cut. But, in respect to their uses and varied construction, we shall have more to say in connection with telegraph instruments in general.

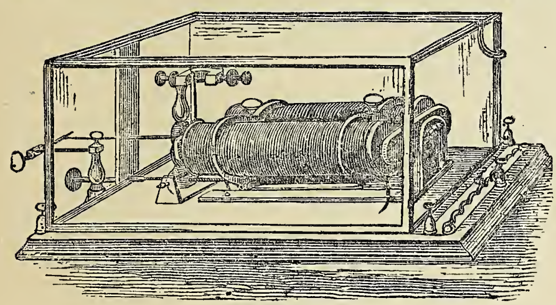


Fig. 236.

We have thus endeavoured to lay before our readers some of the most interesting facts in relation to the "communication of time" through wires, by means of electro-magnetism. The limited space at our disposal has necessarily caused our sketch to be imperfect, considering the extent and interest of the subject: but in a work such as the present, devoted to so many objects, selection must, with brevity, be made a guiding rule.

Sufficient, however, has been said and illustrated to give a general knowledge of the advances that have been made during the last twenty or thirty years, and the valuable objects to which electro-magnetism is applied. In the Observatory, it is of constant use in conveying intelligence from the observer at the telescope, of astronomical phenomena, such as culminations, periods of an eclipse, transits, &c., &c., to the person engaged in noting down the observations. Again, the arrangements that have been described, have been, together with the electric telegraph generally, of the highest value in settling questions of longitude, affording, also, an instantaneous means of communicating meteorological observations. At the present time, the metropolis is, every morning, put into electric contact with all the chief ports, cities, and towns in our islands, and many on the continent; receiving reports of the state of the weather, height of the barometer and thermometer; with other important information of the utmost value to our marine service, to the agriculturist, and society in general; but on these subjects we need not further dilate, as they will be better inquired into when we enter on a description of the electric telegraph.

Another subject of interest connected with electro-magnetism, is that of using the power for the purpose of simultaneously illuminating a number of gas-lamps in a building, when the burners are placed so high as to be out of ordinary reach.

The first attempt, or proposed attempt, that we are aware of, was suggested to us by Mr. Isham Baggs, in 1855 or 1856, for we write from memory. That gentleman was then well known for his devotion to the study of electricity generally, but especially of all matters connected with electro-magnetism and electro-telegraphy.

He proposed to simultaneously light all the stations on a line of railway, by means of a conjoint action of electro-magnetism, and electricity excited by friction; but, so far as our information carries us, it was not till some years afterwards that anything like practical results were obtained. Mr. Hart, an eminent philosophical instrument-maker, of Edinburgh, applied the electro-magnetic method. From memory we give the following description of the plan he adopted. Near to each gas-burner was an electro-magnet, that, on being excited by a voltaic current, sprung up, and placed over the gas issuing from the jet a fine platina wire. This being ignited by a voltaic current, set light to the gas; immediately after doing which, the electro-magnet was automatonically retracted, by which the destruction of the platina wire was avoided, that would or might otherwise have occurred, owing to the impurities of the gas in combustion within, or arising from the flame, such as arsenic, sulphur compounds, &c.

The following interesting account of a method that combines some already described, has been taken from a paper by Mr. H. A. Severn, gold-melter and assayer to the Union Bank of Australia, Melbourne, Victoria; entitled, *Gas-Lighting by Electricity, Experiments, &c.*:—

"A few days prior to the opening of the Intercolonial Exhibition, in Melbourne, during the month of October, 1866, it was found to be a difficult, dangerous, and also a tedious task to ignite the gas-jets in the interior of the roof of the main hall. This portion of the building being some fifty-seven feet above the floor, and there being no means of getting to the sun-lights (gas) through the roof, it became necessary to resort to a long pole, on the top of which was affixed a spirit-lamp. This arrangement was soon found not only to be dangerous and clumsy, but to entail a large waste of gas, inasmuch as the meter, when turned on, passed gas into all the burners; and the pole process, requiring some half-hour to complete, allowed much gas to escape. Electricity appeared to be the only remedy; and, having electrical, galvanical, and electro-magnetic apparatus of my own construction at hand, I determined to carry out, if possible, the ignition of these roof burners by one of the agents above mentioned.

"Galvanism, effecting the ignition of platinum wire within the area of the flame, was the first experimented upon. I used a Bunsen battery of sixteen cells; and when I arranged my experimental jets of gas, I found that only a certain part of the gas for forming the flame could be thus ignited, owing, perhaps, *to a certain mixture* with atmospheric air *there* taking place, and, being more inflammable than the remainder, was thus more easily ignited by the platinum wire.

"On arranging a series of twenty-eight platinum wires for the ignition of a similar number of gas-jets, it became pretty apparent that the ignition of the platinum was affected by numerous causes, such as the inconstant action of the battery, drafts produced by wind, the formation of deposits of carbon, and so forth, on the platinum, and on its junctures with the main conducting wire. These led ultimately to the abandonment of galvanism, as an insecure and uncertain means of realising the object.

"Electro-magnetism was also tried; but the want of constancy, and the insufficient *tension*, led to its being looked upon as far too uncertain for the purpose.

"Electricity by friction, or the ordinary cylinder machine, was the subject of the next experiment; and this, among the numerous trials, appeared to be the most promising and certain.

"I devoted a large amount of time and consideration to the mechanical arrangement of the glass tubes for insulating the terminals and platina poles immediately above the gas-jet. After a series of trials, the conditions required were found to be—1st. Perfect continuity of surface. 2nd. Good insulation for electricity of high tension. 3rd. Perfect steadiness of the platinum poles within the gas that was to be ignited. These three conditions are of paramount importance. Good insulation for high-tension electricity is required to prevent its finding a course of less resistance than is offered by its intended and proper one. A perfect support for the platinum poles is also required. These are only $\frac{1}{16}$th of an inch apart; and, were they liable to movement, the disarrangement would render certain the failure of the whole experiment.

"I determined on keeping my conducting wires in all places of contact, and, where insulation was required, fully three-fourths of an inch from any other conducting medium. Glass tubing was the insulator used.

"The conductor within the glass tubes was made of sheet copper one-eighth of an inch wide, bent into a curve, and inserted into a glass tube. The upper end of the tube was now fused on *one side*, and, while red-hot, pressed sharply against the copper slip; *thus* fixing steadily one end, but leaving the inner surface of the *copper slip free* for conducting the current, the first end named being the one to which I fixed my platinum poles; the glass tube was then again fused, and indented immediately under the bend of the copper slip within it; thus preventing all chance of the copper slip being pulled down, so as to move the platinum, and also forming *a toothing* for the cementing about to be described.

"The glass insulator, and copper slip now fixed within it, are cemented, by means of plaster of Paris (the glass being previously ground rough), into a brass ferrule screwed on the outside, leaving the indented portion of the glass about a quarter of an inch above the ferrule. Immediately on each side of that portion of the pipe from which issues the jet it is intended to ignite, are brazed, or clamped, two short horizontal arms carrying two ferrules, with female screws to receive glass insulators; and the ferrules previously described, containing the tubes with the copper slip, are now screwed into the ferrules on the gas-pipe, until about three-quarters of an inch of glass remains at either end; the upper part of the outer ferrule, which surrounds the *indentation* on the glass tube, is now filled with plaster of Paris, which, on setting, renders it impossible to move the tube or copper slip. It will be seen that this particular mode of fixing the glass insulators is very well adapted to ring-burners that are already fixed in their places; is safe; and will also bear a fair amount of rough work, without in any way risking an alteration in the *distance* of the platinum poles. The platinum wires, poles, or terminals were merely twisted around the pole end of the copper slip, and brought within $\frac{1}{16}$th of an inch from the pole on the opposite side of the burner.

"The first conducting wire was taken from the outer coating or side of a Leyden jar to the opposite pole—plus—down to the floor of the hall, and so on; the last or plus pole being carried (and insulated) along back to the interior, or plus pole of the jar, for completion of the circuit. The total length of wire was 480 yards. This arrangement of my wires, in the event of non-continuity, would, it will be perceived, enable me to discover, with very little trouble, where the derangement was situated, should one take place.

"On charging the Leyden jar, and completing the circuit, the well-known brilliant snapping spark, of about three-quarters of an inch, took place; the gas was now turned on, the spark made, and the ignition perfect. This was retried several times; out of nine trials, notwithstanding that the spark was good, and therefore sufficient for lighting the gas, one or two of the *ignition* jets did not light. On making and discharging another charge, perhaps one of the two was ignited, the remaining one requiring, perhaps, yet another charge specially for its own use. The actual cause of this anomalous result I was at a loss, for some time, to conceive, until I suspected that it might be caused by the draught blowing the gas, at the instant of the spark, away from its immediate proximity. The platinum poles were about three-quarters of an inch above the top of the jet; this gave a good leverage (if I may use the term) for the wind to act upon. I therefore determined to reduce the height of the spark from three-quarters of an inch to half an inch; this very materially assisted in rendering one discharge equal to the

task of igniting the five burners with certainty; but even so, on one or two occasions, *one* has missed fire until another spark could be sent through.

"Having thus seen the desirability of transmitting a number of sparks in rapid succession, in order to catch the gas, if possible, while passing and repassing the space traversed by the one spark, I determined on charging several jars; and this led me to the construction of what I have called a successive-discharging Leyden battery (new, I believe), whereby I charge but one battery, and then obtain a series of discharges succeeding each other at any speed I desire. My new form of battery is composed of six Leyden jars, placed on a circular board covered with zinc, and to which are soldered hoops or circles of zinc to receive the bottoms of the jars; the knob or ball of each jar has a cup-shaped hole in its top, for holding mercury; the six jars are covered by one lid made of dry wood; the rods and balls are put in their places, and the cups filled with mercury: this completes this portion of the battery. I have now a brass ring, to which are soldered on one side six wire pins one inch long; each of these pins rests (when put on) in one of the mercury cups, and thereby connects the six jars, and enables me to charge all at once; when charged, the ring, by means of an insulated handle, is lifted off—thus at once insulating each jar, and giving me a battery of six distinct jars. On the centre of the cover to the jars is fixed a revolving insulated arm, terminating in a brass ball, and reaching within one-eighth of an inch of the six balls around it; the upper end of the axis of the revolving arm terminates in a mercury cup, and the axis itself is covered by glass for insulation. On fixing the negative or one of the conducting wires with the zinc stand, placing the other in the central mercury cup, and causing the arm to rotate, a beautiful succession of sparks takes place, at a velocity equal to the speed of the revolving arm, and thus insuring six flashes in rapid succession, and the effectual ignition of the gas.

"Since the completion of this arrangement, the gas has always been ignited with *perfect* success. In thus describing, in a brief manner, the means adopted for the successful completion of a most desirable object, it must be borne in mind that the building was at the time full of delicate articles, and that manipulating the gas on the top of a ladder fifty-four feet high was both dangerous and inconvenient. Should the details and facts I am now able to put before you in this short paper (together with the sketches appended hereto) prove acceptable and useful, my object will be gained, tending, as I trust my paper may, to open up practical experiments and discussions on a branch of applied electricity that has remained dormant already too long."

The following account of Mr. Severn's ingenious plan is extracted from the *Melbourne Argus*, of 19th November, 1866:—

"An experiment worth record has just been successfully made in the Exhibition building by Mr. H. A. Severn, assayer to the Union Bank, the object being to light the gas 'sun-lights' in the roof by electricity and galvanism. Some three days prior to the opening of the Exhibition, it was discovered to be highly inconvenient to light these burners, fifty-three feet above the floor. There were five sun-lights to be reached from the ground, and each light had twenty-eight jets, so that the desirability of finding some other mode of igniting the burners became very great. In preparing the apparatus for lighting by electrical means, Mr. Severn took much pains, and spent a vast deal of labour; for to avoid risk of failure, he determined upon having four more jets placed in each ring, which, filling up the breaks, made the ignition of one jet in that ring sufficient for all, as the flame would spread. The burners had to be brought down each night after the public were shut out; and as all had to be done amid a legion of glass cases, and work continued far into the small hours, great credit is due to Mr. Severn (who was indefatigable in his exertions), and to his assistants. On Saturday morning the apparatus was complete; the five lights were ignited seven times consecutively; and on Saturday evening the success was equal, although the charge or flash runs through some 500 yards of copper wire, the points of ignition being, of course, of platinum."

One objection that we suggested to the success of Mr. Bagg's proposed plan (mentioned at p. 425, *ante*), was, that it would be impossible, on a long line of railway, to depend on all the gas-lights being ready for lighting at the same moment; as it would necessarily happen that, at some stations, excess of business, neglect, or other cause, would prevent, perhaps, a burner or more being turned on. But after having seen Mr. Hart's plan in action, and perusing the account furnished by Mr. Severn, we may reasonably conclude that such matters of detail would be overcome by persevering ingenuity. It is a common lecture-table experiment to light gas, or even a candle, by voltaic electricity; and since the intense and quantitive power of the induction coil have been developed, such difficulties might be easily overcome, and a valuable practical result obtained.

CHAPTER XIV.

DIA-MAGNETIC PHENOMENA, AND THE LAWS OF DIA-MAGNETISM.

FEW will question that, when Faraday discovered the phenomena of dia-magnetism, he made one of the most interesting additions to our knowledge of the forces of nature.

Philosophy of an experimental character must always be in a state of transition. The *accurate* knowledge of one period, may be proved false in a succeeding one, either by new discoveries, or by more exact generalisation. Hence progress in experimental science is its great characteristic.

Cynics will, consequently, object to the pursuit of science, that, if it is progressive in character, it can never be exact; but the objection is more apparent than real. It must be borne in mind that our powers, as intelligent beings, in the study of nature, are constantly at work in the measurement of the powers of Nature's Creator: in other words, finite intelligence is constantly striving to measure its powers with infinite intelligence; and if failure is frequently the result, it is no discredit to human nature—indeed, it simply indicates greater success.

The tendency of natural philosophy, as an intellectual pursuit, whether experimentally or theoretically, has, during the last half century, been one of constant approximation to, and occasional arrival at, truth. Davy and his contemporaries *guessed* at, Faraday *demonstrated*, and their successors *proved*, truth in many branches of experimental science; and if, up to the present time, our success in investigating the powers of nature has been but partial, still, for the period just named, it has been enormous.

These introductory remarks are especially pertinent to the subject of this chapter; for the discovery of dia-magnetic phenomena has led to far simpler views of natural forces, their correlation, &c., than had previously been attained to; and as simplicity of law and action is a sign of philosophy, it follows that the discovery to which we have alluded cannot but be considered of the highest importance.

Formerly it was thought that electricity could only be attained by friction, as of glass or resin; but the discoveries of Volta, and the admirable researches of Faraday, proved that chemical action is a much more abundant and manageable source of that force. Magnetism, again, was considered simply as an affection of bodies entirely, or in part, composed of iron; as, for example, temporarily magnetised soft iron, permanently magnetised steel, or the natural oxide of iron, known popularly as the loadstone. But, further, as Faraday extended his early researches, he proved, as we have already shown, that, whilst a current of electricity passed round a piece of soft iron, it was capable, under certain circumstances, of engendering magnetism in soft iron or steel. On the other hand, he also showed that magnetism, under certain other circumstances (already described), was equally capable of producing quantitative and intense electrical effects. By means of the induction coil (already so fully described), we have been enabled to associate, simultaneously, the effects of static and dynamic electricity with those of magnetic induction; and, still more recently, Mr. Wilde has shown, that a kind of successive series of electric and magnetic inductions may be made to produce effects of a luminous, calorific, and other nature, far eclipsing in power and brilliancy all that had been previously attained.

Hitherto, in this rapid sketch of the advances of physical science, we have only glanced at the relation of electricity and magnetism; but if we advance for the moment but a step further, we shall extend largely the field of our operations.

The powers of electricity and magnetism, in producing light and heat, have been frequently the subjects of description in the preceding pages; especially in relation to the fusing of metals, and the production of the electric light. But Faraday carried matters a step further; he showed that a ray of polarised light was itself obedient to the power of magnetism; and that, under circumstances hereafter to be described, such a ray might, by magnetic action, be directed from its course as readily as the magnetic needle may be deflected by a current of electricity, or attracted and repelled by the pole of another magnet.

The astonishing point in this discovery is this. We can naturally well understand the action of force on force by the agency of matter. Thus it is no reason of surprise that if two elastic balls come in contact, a change in the direction of motion of one or both should ensue. Daily experience compels us to arrive at such a knowledge.

But magnetism and light are such refined powers as entirely to escape or elude the detective ability of all our modes of measurement when not associated with matter. Hence, when we find that magnetism can change the direction of a ray of light instantly, we seem to enter into a new phase of philosophy, as new and as untrodden as were electricity and magnetism a century ago.

It is extremely interesting to trace the mental progress, or steps, by means of which such a man as Faraday was led from one discovery to another; and we have never met with a case so

interesting as that which led to the discovery of dia-magnetism by him. Nothing but a careful perusal of his three volumes of *Experimental Researches* will suffice to give the reader an idea how that philosopher finally hit on this interesting result. We can scarcely, with the least hope of success, attempt to indicate to the general reader how each step was taken antecedent to the arrival at the general result. It seems, however, so far as we can offer any opinion, that, in the first place, Faraday arrived at very precise results in regard to the relation of static induction, conduction, and insulation. Next, that his view of induction led him to consider dynamic electricity, as of the voltaic current, consequent on the discovery of the deflection of the needle by Œrsted, capable of producing magnetic affections. As a corollary of this electro-magnetic induction, magneto-electric induction would necessarily follow; for, as Faraday and others showed, and as we have illustrated in the article on electro-magnetism, magnets might be made to revolve round electrified wires, and the latter equally so around the former.

But, as we have already seen, whenever a break is caused in the continuity of electro or magneto currents, light and heat are, under most circumstances, produced. Hence it became natural to expect that some relation should subsist between the four forces of heat, light, electricity, and magnetism. Faraday, however, was still further successful; for, enlarging on some experiments of Coulomb, Herschel, and others, he showed that a copper plate or disc, in motion, could be arrested by induced magnetism, as produced by the electro-magnet; and, conversely, that a copper disc, during rotation, could also produce dynamic electricity sufficient to deflect a magnetised needle.

Correlatively, it might be supposed that both light and heat could be affected by magnetism; and it is at this point that we may now enter on Faraday's early experiments on dia-magnetism, by which he eventually proved that light, and all forms of matter, are subject, similarly or dissimilarly, to the power of magnetism.

But before proceeding to details on this subject, it may be remarked, that since Faraday published his early results in reference to dia-magnetism, extended observations have led us to much more enlarged views of the relation of natural forces, and especially in respect to what we may call universal magnetism. Even gravitation has been considered only as a form of magnetism, analogously to what we consider as the relations of electricity and magnetism. The diurnal and other periodic variations of the magnetic needle have also been connected with many other natural phenomena—not by guess-work or theory, but by actual and accurate observation. Hence, as we shall subsequently point out, each and all of the forces of nature have been so traced, individually, collectively, and relatively, that we seem to be getting, at a comparatively rapid pace, nearer to the goal of simplicity, which, as we have already stated, is the final object of all investigations into natural phenomena and laws.

Light, its Nature, Laws, Etc.

To explain fully the effects of magnetism on light, we must first consider the general character of that agent.

Under the former—and still, to some extent, used—definition of light, it was considered to be, and termed, an imponderable agent; that is, the most sensitive of our balances could not appreciate its presence: in other words, unlike any form of matter, it could not be weighed. Two theories have pre-eminently been adopted to explain its nature: the first was the *corpuscular*, or that which supposes light to be a series of successive emanations from luminous bodies, such emanations being of a very subtle, refined, yet material character.

Opposed to this theory, in every possible respect, is that termed the *undulatory.* This supposes light to result from the undulation or wave-like motion of a suppository ether; suggested as filling all space, the pores of all bodies, gaseous, liquid, or solid; and, in fact, of universal occurrence, so far as relates to all observations capable of being made by man. The truth of the latter theory is amply based on the fact, that the length of such undulations have been accurately measured in fractions of an inch, and their numbers, occurring million on millions of times in a second, have been counted with great approximate accuracy. Hence the undulatory theory of light is that which has received the greatest countenance or support from all modern philosophers, although certain difficulties occur in its universal application or adoption.

Under the considerations or conditions of the undulatory theory, light is supposed to proceed from a luminous body, in constant wave-like (hence *undulation*, *undulatory*, &c., from the Latin *Unda*, a wave) progress, to the object illuminated by it. These progressions of waves take place from the luminous point in direct lines, provided no interfering causes (to be presently dealt with) interrupt the passage of the undulations. Hence light, like heat, electricity, and magnetism, is a *radial force;* or, in other words, passes, like the *radii* or spokes of a wheel, in straight lines from the centre to the circumference.

One of the simplest illustrations of such waves or undulations, is seen in those produced by throwing a pebble into still water. From the point of contact between the stone and the liquid, series of circular waves are instantly produced, at first small in diameter, but gradually increasing to an apparently unlimited diameter or circumference—the limit, theoretically, being that of the area of the disturbed surface of water. So a ray of light, thus starting, say from the sun to the earth, or a set of luminous undulations (which is more correct), go on in constantly increasing circles of undulation until the luminous diameter of such a circle, at the surface of one, has the enormous extent of upwards of 180,000,000 of miles.

The speed at which these undulations occur is as marvellous as their number. At a previous

page we have given estimates of the speed of electricity along a conductor. That has been variously estimated from about 288,000 miles per second to only a fraction of that amount. The reasons of the discordance in the results have been fully explained at the page just referred to. In estimating the speed of light through space, however, we have much surer data to rely on. The eclipses of Jupiter's satellites, a phenomenon of constant occurrence, aid us materially in calculating or estimating the speed of light. It must be first presumed that we can, by astronomical methods that need not be here explained, calculate, to a second of time, when an eclipse of any body of our planetary system *should* take place. We remark emphatically on the word *should*, because, whilst the predicted and actual occurrence of a solar and lunar eclipse never need vary a fraction of a second, the eclipses of Jupiter's satellites, as seen and calculated, vary greatly, unless correction be made for the time taken or required for the travelling of a ray of light after the ending of the eclipse.

In other words, at the moment of the ending of an eclipse of one of those satellites, it does not reappear to the eye of the observer on the earth, simply because its light takes a certain length of time to travel to the earth. Again, at different parts of the earth's orbit, the length of time required for the reappearance of the satellite varies, simply because, in the revolution of our earth and Jupiter round the sun, the relative distances of the two planets increase or decrease for obvious reasons.

It is evident, therefore, that knowing the distances which Jupiter and our planet are apart at two different periods of the passage of our earth in its revolution around the sun; knowing, again, the difference of time required for the reappearance of an eclipsed satellite of Jupiter; and also having an accurate knowledge of the mean distance of the earth and of Jupiter from the sun, we have all the elements of time and space requisite to calculate the speed of light: and from this and other considerations, arising from terrestrial experiments of Foucault, Wheatstone, and others—that we shall not stop to describe—it is now generally considered that the speed of light through space is at the rate of about 185,000 miles per second.

We have stated, that if no interfering cause occurs, light will continue to pass through all space in straight radial lines. But interfering causes, such as *reflection, refraction, polarisation*, &c., that we must now particularise, all prevent that result; and Faraday added another, in the shape of magnetism, when he first magnetised a ray of polarised light.

Reflection must be first considered. When a ray of light falls on a plane surface, it suffers precisely the same results as occur when an elastic ball impinges on such a surface; that is, it is reflected at an angle equal to that at which it impinges. If the ray or ball fall perpendicularly on such a surface, then the reflection or throwing back of each is vertical. This can be plainly illustrated by any ball, but especially one of india-rubber, which, on account of its elasticity, is especially suitable for such a purpose.

If, however, the ray of light or india-rubber ball impinge obliquely on a plane surface, then the angle at which either will leave the surface will be precisely equal to that at which each impinged or fell: in scientific language, it is therefore stated, that the angle of incidence (or falling on), and the angle of reflection (or leaving of the plane surface), are equal. One of the simplest modes of illustrating this fact is found in the game of *Bagatelle*, in which the art of driving a ball into a cup depends on this principle.

In the following cut, this law of incident and

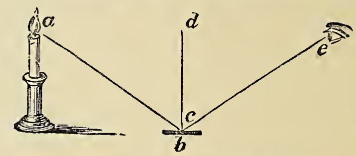


Fig. 237.—Reflection of Light.

reflected light is illustrated. *a* is the source of light, from which a ray passes to *b*, the reflecting surface; *d c b* is a perpendicular line; *c a d* is the angle of incidence; and *c d e* the angle of reflection, the ray proceeding from the flame, *a*, by the reflecting surface, *c*, to the eye of the observer at *e*. It will be evident that the angles of incidence and reflection are, consequently, equal; and the proof of this is easily arrived at by a very simple method. As in the cut, a common candle may be employed for the source of light, a sperm or "gas" candle being preferable for the purpose; the reflector, *c*, may be a small surface of mercury, or, what answers equally as well or better, a basin of treacle. The measurement of the angles will be found unnecessary, as the observer, by the simplest notice, will be convinced of the facts and laws that have been stated.

Of course, for our present purpose, this glance at the science of optics will, and must be, of the most superficial nature. All that is proposed here is to put the general reader in possession of such facts as will enable him to understand the phenomena of dia-magnetism, so far as the magnetisation of light, first effected by Faraday in 1845, is concerned; and, consequently, we do not here commit ourselves to even an elementary view of optical science. We therefore, briefly, next consider the nature of simple refraction.

In this respect we confine our remarks only to decidedly transparent media, because these alone have hitherto, in regard to the magnetic affections of light, been dealt with.

If a ray of light pass perpendicularly from its source through a medium of equal or homogeneous structure, such as glass, water, air, or the like, it proceeds in a straight line. If, however, it pass from water to air, air to water, air through water, glass, &c. (because the density of the media differs), the course from one medium to another will *not be* in a straight line throughout the passage of the ray, should the

latter not impinge perpendicularly on the surface of a fresh medium.

For example—If a piece of silver, or any other coin or object, be placed in a basin of water, and be viewed *exactly in a straight line over it*, the object will appear precisely the same as when in the hand. If, however, it be viewed obliquely, then its appearance will be changed. Similarly, if a stick be placed in an *exactly upright position* in a pail of water, it will appear straight; but if it be introduced obliquely into the water, that portion that is in the liquid will appear to diverge out of the straight line, and seem nearer to the eye than the portion that is held in the air. Similarly, in looking obliquely into a trough of water, pond, or river, the bottom of the receptacle, at a distance from the eye, seems equally near, or even nearer to it than that which is really so; and hence have arisen many fatal accidents through eye-errors of this kind. As a matter of general precaution, if standing on the edge of a stream, with its bed in view, it is safe to estimate the *apparent* depth at only two-thirds of the *real* depth; or, in other words, a river or pond so viewed, although apparently, say six feet deep, may nearly be nine feet.

Now this result simply arises from the effects of refraction—in such cases termed *simple refraction*, in distinction to double refraction, hereafter to be more particularly described. By *refraction* of this kind or character, is simply meant the bending of rays of light out of their straight course as they pass from one medium to another. In viewing an object from a room, with the window open, opposite objects appear exactly, or practically so, in a straight line from the eye. But if the window be shut, and the glass comprising it be "wavy"—that is, full of *striæ*—owing to the unequal refraction of light by the glass, compared to that of the air (which, as in the case of the open window, is so trifling that it may be neglected), the opposite objects dance, or seem to dance before the eye as that organ is moved to and fro, according as the direction of these *striæ* exists. Plainly, and in few words, when a ray of light passes from a light through a dense medium, or *vice versâ*, it ceases to pass through or by straight lines, the latter becoming more or less curved in the whole or part of their direction.

A common magnifying-glass is one of the simplest illustrations of the fact. It is well known that, if an object be viewed through a piece of good flat flint glass, if very thin, it appears precisely the same to the eye as if the glass were not interposed. But if the glass, in place of being perfectly flat, be curved on one or other of its sides, the light converges to a point, on the opposite side to that at which it enters the glass to an end, called a focus. This is easily demonstrated by holding a common magnifying-glass in the rays of the sun; for it will be seen that, although they must necessarily enter the magnifying-glass in parallel lines, still, on the other side to that at which they enter, they do not remain parallel, but gather together into a small point, at which the total of light and heat is concentrated. This is a result of the single refraction of the rays of light; and on this principle depends the construction of the telescope, microscope, and all other philosophical instruments in which lenses are employed.

As still further explanatory of what has to be said on Faraday's experiments on the magnetism of a ray of light, a few words must be said in respect to the colour of light. Many beautiful illustrations of this might be adduced, but we must here confine ourselves to the most essential.

The chief source of light is the sun; and the solar luminous rays are always accompanied by calorific rays, which can, by certain means, be separated from each other. Light, again, like heat, is found in a latent state in all bodies; and by mechanical, electrical, and chemical means, can easily be brought out so as to be perceived by the senses.

The light afforded us by the sun is called white light; but by a very simple arrangement it can be decomposed, and resolved into numerous rays of various colours. For this purpose a prism is employed, which is a piece of glass, of a triangular shape; and on a ray of white light being allowed to pass through it, the component rays are easily separated from each other, and may be received on a sheet of paper for complete examination.

The following figure illustrates the most convenient mode of carrying out this experiment.

A ray of sun-light (*a*) is allowed to pass into a darkened room, through a hole in a shutter

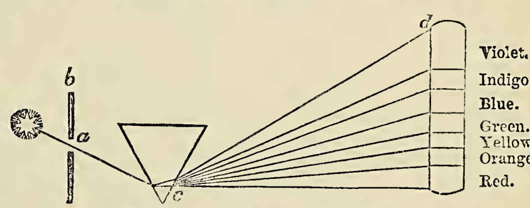


Fig. 238.—Prismatic Spectrum.

(*b*), and to impinge on a glass prism (*c*). The light, on emerging from the opposite side of the prism, will be divided into numerous rays, having at least seven different colours—namely, red, orange, yellow, green, blue, indigo, and violet. They are observed in the order in which we have arranged them; the red being always the lowest in the series, and the violet at the upper end. An image of coloured light so formed, is termed a spectrum (*d*); and each of the rays varies, both in respect to its luminous and calorific effects, as we shall perceive in our further remarks.

We have stated that seven different coloured rays may be thus produced; but, by careful examination, it will be observed that four of the colours are produced by the overlapping of the other three. Hence, perhaps, in strict truth, we only discover *three* primary colours in a ray of light—namely, blue, yellow, and red. Thus, green is at once formed by combining yellow and blue; the orange ray, by uniting red and yellow; the violet is a combination of

red and blue ; and the indigo is produced by an intensification of the blue rays. Of late years it has been suggested that only one primary colour (yellow) exists, from which all others are derived.

In explaining the phenomena of the prismatic spectrum, we can happily call in the doctrine of undulations (see *ante*, p. 429) to our aid ; and we find that the extreme violet rays are produced by a greater number of undulations taking place at that part of the spectrum, than at the place where the red rays are evident. The subjoined table gives the length of these undulations for each ray of the spectrum.

Colour of Rays.	Length of the Waves in decimal parts of an Inch.	Number of Undulations in an Inch.	Number of Undulations per Second in Billions.
Extreme Red ...	0·0000266	37640	458
Red..................	0·0000256	39180	477
Intermediate ...	0·0000246	40720	495
Orange	0·0000240	41610	506
Intermediate ...	0·0000235	42510	517
Yellow	0·0000227	44000	535
Intermediate ...	0·0000219	45600	555
Green................	0·0000211	47460	577
Intermediate ...	0·0000203	49320	600
Blue	0·0000196	51110	622
Intermediate ...	0·0000189	52910	644
Indigo	0·0000185	54070	658
Intermediate ...	0·0000181	55240	672
Violet................	0·0000174	57400	699
Extreme Violet	0·0000167	59750	727

It will at once be perceived that a great difference exists in the number of undulations which produce the different coloured rays of the spectrum ; and we should here remark, that the luminous rays in which certain chemical phenomena of light are produced, are those of the violet end ; whilst those in which the heating effects are most observed, are placed in the red terminal of the spectrum. This is a point of great importance, were we to enter into the investigation of the chemical effects of light, usually comprised under the head of Photography, and its applications.

If any coloured substance be placed in any of the prismatic rays, it will immediately assume the colour of that ray ; and hence we perceive, that the cause of the colour of bodies is due to the absorption of all the rays of the spectrum but that which they reflect from their surface.

Whilst by means of a prism we can decompose white light, and produce its colours, an experiment may be tried by which the colours can be reunited, and white light at once be reproduced. For this purpose, another prism is to be placed on the one by which light has been decomposed, so that the two may form together a square. The ray of light will pass through without suffering much change. Indeed, the two prisms thus become equal to a solid piece of glass. A slight amount of colour may be visible ; and this is owing to the refraction of light occurring when it passes through a dense from a rarer medium—a phenomenon of constant occurrence in all artificially-made transparent bodies.

Another mode of illustrating the recomposition of white light, is by painting on a circular card the different prismatic colours, in divisions extending from its centre. If the card be made to rotate rapidly on its axis, a kind of grayish-white colour is produced. This experiment is often employed at the lecture-table, for the purpose of illustrating the composition of white light.

In reference to the cause of colours, we may add, beyond the observations just given, that, independent of reflection from a surface to which we have just assigned generally the cause, together with the absorption of all other rays, is that seen by the polarisation of light, to be hereafter more fully described ; and interference of light must also be taken into account.

One of the simplest methods of studying colours in reference to their production at will, is that of the soap-bubble—simple in itself, but as yet even but partially understood ; for, at the meeting of the British Association in 1867, the late Sir David Brewster, whilst suggesting new views of the cause of those colours, yet left the investigation incomplete. We believe it was the last scientific research that he engaged in ; for from that meeting he was removed in a state of syncope, not long after followed by his lamented decease.

We may, however, suggest very simple methods, by means of which the nature of colours produced by thin plates of air, &c., and that of complementary colours, may be studied.

Every one must have noticed, that when oil, tar, and other liquids, are dropped on the surface of water, a variety of beautiful colours is produced. Sir Isaac Newton, by forming thin plates of air through pressing two glass surfaces together, was enabled to measure the thickness of these plates for each colour afforded. As these results are of great importance, we give directions, by following which the student may easily reproduce them at his convenience.

The general character of colours produced independently of what is seen in naturally coloured objects—such as flowers, dyed materials, the feathers of birds, &c.—may be conveniently and easily investigated by the following methods :—

Place a glass lens, of focal length of ten or twelve feet, on a flat plate of glass, and press the two surfaces together. It will be observed, that if great pressure be employed, a small dark spot will be produced at the point where the two surfaces are nearest each other ; and round this point a series of concentric circles will be formed, each being of a definite colour, and varying from violet to red.

Boil some water in a Florence flask, or other glass vessel, and throw into it a piece of Castille soap. When steam issues from the neck of the vessel, and all the air has been expelled, cork the flask so that it shall be air-tight. On shaking up its contents, thin films will be formed, presenting a similar set of appearances to those named in the last experiment.

Now, the production of these colours is due to the fact, that the plate of air or film of the soap-bubble is of exactly the thickness required to produce the colours observed. If the plate be

exceedingly thin, then no light will be reflected, and the spot will be black. If somewhat thicker, then violet light will be perceived; and so on until the plate becomes of greater substance, when red light will be reflected from the surface, and so reach the eye.

If, however, the observer look *through*, instead of *at*, the plate of glass, he will see what are called the *complementary* colours, which, combined with the colour observed, would produce white light. These experiments enable us to tell the thickness of a plate of air, and, therefore, the length of an undulation of light of any colour; for we have only to learn the distance between the lens and the flat glass at any point where we notice a colour whose undulation we wish to study, when the length of the undulation is of course obtained. This is easily done; for, knowing the size of the circle of which the lens forms part, we can at once learn the length of any arc of that circle; and, taking the length of the tangent of that arc in which we observe the undulation existing, we can obtain the thickness of air between the tangent and the curve of the circle.

This will be easily understood by referring to Fig. 239, in which *a b* represents a flat glass plate, resting against a lens, *d d*, which forms part of a sphere, whose centre is *c*. Let *f f* be the extremities of a ring of coloured light distant from *e*, which is a point where we will suppose a black spot, or place where no light is reflected; *e f* is, of course, the tangent of the angle, *f c e*. Now, *f g*, the thickness of the plate of air, will evidently depend on the angle which *f* forms with the radius of the circle, *c e*. The length of *c e*, *c g*, being easily obtained by ordinary measurement, *f g* is, of course, as easily found. It follows, that the smaller the angle existing with respect to the centre of the circle, *c*, the thinner will be the plate of air between the lens and the glass plate, *a b*. As the measurement of all intermediate distances involves only the ordinary rules of mathematics, the student will at once perceive that we can thus calculate the thickness of any coloured plate; and, therefore, infer the length of an undulation of any ray of light under examination.

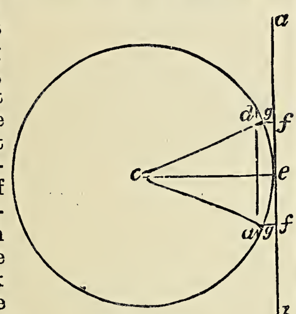


Fig. 239.

From these simple experiments, we arrive at the measurement and lengths of an undulation of light, already frequently referred to in the previous pages, but more particularly so at p. 432, *ante*, where a table of such measurement was given. Thus, if we observe that a soap or oil film presents the same colour as that which we find at any part between the lens and the glass plate, we at once infer that the thickness of each is equal. There is, however, a limitation of the law, which we must carefully bear in mind. It is, that the thickness of plates of different materials reflecting the same coloured light, is inversely as the ratio of their index of refraction. Hence plates of various transparent media, such as air, water, glass, oil of cassia, &c., are of different thicknesses when producing similar optical coloured effects.

We append a rough illustration of the position of the colours as observed between the lens and the plate, and a table of the thickness of the coloured plates; but must here state, that for the sake of simplicity, we have confined the attention of the reader to the production of only one order of rings. There are, however, several of these produced. The relative thicknesses and positions of the first order are pointed out below, and represented in the annexed engraving. In Fig. 240, *a* represents the lens placed on the glass plate, *b*, and *c* is the interval existing between the two. In the following table, the numbers in the figure above indicate the position of the reflected colours placed before them; and the thicknesses of these are also given for the series of rings, commencing from the nearest or central point of contact.

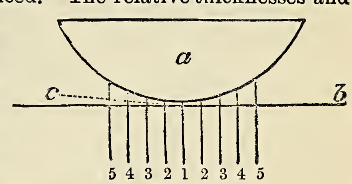


Fig. 240.

	Colour.	Thickness in parts of an Inch.
No. 1 . . .	Black . . .	·000005
,, 2 . . .	Blue . . .	·000024
,, 3 . . .	White . . .	·000052
,, 4 . . .	Yellow . .	·000071
,, 5 . . .	Red . . .	·000090

The above being the reflected colours, it follows that their complementaries will be seen by transmitted light.

The means of measuring the length of an undulation being obtained, we can next proceed to calculate their speed. We have already given a table of these (see *ante*, p. 432); to which we now refer, whilst we enter into their calculation in detail.

Having found the length, in parts of an inch, of an undulation, and knowing, by the eclipses of Jupiter's satellites (see *ante*, p. 430), that light travels at the rate of 185,000 miles per second, in round numbers—it follows that there will be as many undulations of any coloured light, in a second of time, as there are parts of an inch equal to the length of one wave in a distance of 185,000 miles, which the ray has travelled during one second.

We have previously mentioned (see *ante*, p. 432) that an extreme red ray has a length of undulation of 0·0000266 of an inch; and if we divide 12165120000, the number of inches in 192,000 miles, by this length of undulation, we obtain the result of about 458 billions of vibrations in one second of time, as producing the extreme red ray of the prismatic spectrum. The same result is afforded by multiplying the

number of undulations per inch by the number of inches in 192,000 miles. Thus :—37640, the number of undulations per inch for the red ray, multiplied by 12165120000, the number of inches in 192,000 miles, gives 457,898,116,800,000 as the number of undulations per second of a ray of red light.

We cannot fail to be impressed with the astonishing minuteness and rapidity of the undulations which produce the magnificent effects of colour; and perhaps can scarcely point out any instance in the range of science, in which so great a number of proximate causes is constantly required to produce one well-known, and therefore, perhaps, often unappreciated result.

We need scarcely add, that the undulations of each of the other coloured rays are calculated in a similar manner for every band in the spectrum. As a matter of practice, and to impress the laws which we have been here illustrating, the student will do well to continue these calculations of the speed of each undulation, taking the table before mentioned as a guide, and as affording the requisite data.*

The subject of complementary colours may be still further illustrated thus :—If the eye watch intently a colour for some time, and then be directed to a white surface, an image of the first-seen coloured object will appear, that will be of the colour complementary to that first noticed. Thus, if a red wafer be placed on a sheet of white paper, and be looked at intently ; if the eye be then directed to another sheet of white paper, an image of a green wafer on the latter will be seen. A still more simple, or common example, may be noticed on the bills placarded in the street. If a deep red or orange bill be intently regarded for some time, then, on the eye being removed from it, all surrounding objects will have a greenish tint. This is due to the *complementary colour* appearing to the eye—a circumstance which, we shall presently see, is an important phenomenon in certain affections of polarised light, and also in connection with Faraday's discovery of dia-magnetic phenomena.

The following is a short list of colours mutually complementary.

Table of Complementary Colours.

Colour of Object.	Its Complementary.
Violet	Yellow
Indigo, Blue	Orange
Green	Red
Yellow	Violet.
Orange	Blue
Red	Green.

The above, however, is but approximate in practice ; simply because, as regards all ordinary objects, the power of individuals, in respect to the proper recognition of colours, so greatly varies in accuracy.

In fact, the only real test of complementary colours is afforded by the changes of colour that occur in the use of the polariscope, arising from interference of polarised light, that will be subsequently explained. Another question, relating to complementary colours, or rather their perception by individuals, arises from imperfection of vision. Many persons cannot appreciate natural colours as is done by common consent of the majority of mankind. The celebrated chemist, Dalton, afforded a striking illustration of this fact. Hence the term *Daltonism*, that has been infelicitously adopted to express such peculiarities of vision.

In the preceding remarks we have used the term "index of refraction," which must here be explained, more especially as the subject largely bears on the success of Faraday in his magnetisation of light ; using, as we shall hereafter point out, a silicated borate of lead as the "dia-magnetic," by means of which his first experiments on the subject of dia-magnetism were tried.

The index of refraction of any substance is the ratio which subsists between the angle of incidence and the angle of refraction of a ray of light passing from one medium to another, each differing in density; as, for example, that afforded in respect to air and water, in regard to a stick obliquely introduced into the latter liquid, in the experiment suggested at p. 431, *ante*. This ratio, or index, is *in proportion to the sines of* the angles—a term that requires some explanation for the use of the unscientific reader.

For this purpose we shall have to call to our aid some of the laws of the science of trigonometry. In the annexed diagram we have a circle, in which are drawn several lines (see Fig. 241).

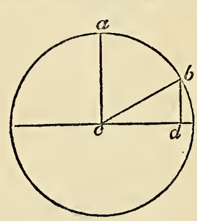


Fig. 241.

The lines $a\ c$ and $c\ b$ are termed radii ; and stretch, like the spokes of a wheel, from the centre of the circle to its circumference. The line $b\ d$ is called the sine of the angle $c\ b\ d$; and it is to this line that we have to call attention, in reference to the index of refraction.

In the following diagram we have a circle, in which are drawn two angles (see Fig. 242).

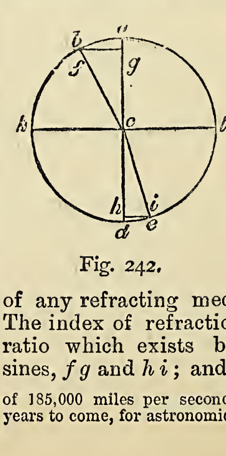


Fig. 242.

In this $a\ c\ b$ represents the angle of incidence of a ray of light entering a dense medium ; and $d\ c\ e$ the angle of refraction. Now the straight line, $f\ g$, is the sine of the angle of incidence, and line $h\ i$ the sine of the angle of refraction ; presuming that the line $k\ l$ represents the surface of any refracting medium, such as water, &c. The index of refraction is found by taking the ratio which exists between the two lines, or sines, $f\,g$ and $h\,i$; and the ratio varies for dif-

* The calculations were made on the old data of the speed of light, as at the rate of 192,000 miles per second. The estimate of 185,000 miles per second cannot be verified, for several years to come, for astronomical reasons.

ferent substances, as we shall see by the following table, which gives the index of refraction for several bodies :—

Table of Indices of Refraction.

Refracting Medium.	Index of Refraction.
Vacuum	1·000000
The Atmosphere	1·000294
Ice	1·308500
Water	1·336000
Alcohol	1·370000
,,	1·374000
Florence oil	1·485000
Camphor	1·500000
Plate glass	1·514000
Crown ,,	1·526000
,, ,,	1·533000
Brazil pebble	1·532000
Rock crystal	1·547000
,, ,,	1·568000
Amber	1·547000
Flint glass	1·578000
,, ,,	1·601000
Sulphur	2·148000
Phosphorus	2·260000
Diamond	2·439000
,,	2·470000

In the above table it will be seen that a gradual increase is exhibited in the refractive powers of various bodies stated. Now, in the construction of all forms of lenses, and many other transparent media for optical research, it is a matter of great importance to employ a body of very high refractive power. Consequently, the diamond, if it could be conveniently worked into shape, would be invaluable as a lens in the microscope, because of its high refractive power. But the great hardness of that gem, and its enormous expense, preclude such a possibility. Other gems of less hardness, but of great refractive power, have been so employed.

In 1830, Faraday occupied himself in many experiments on glass, but especially in respect to getting a highly refractive one suitable for optical purposes. It was requisite that such should be perfectly homogeneous in its structure (a condition that is not absolutely attainable under any circumstances by the hand of man, as Faraday pointed out); that it should be transparent, and as highly refractive as possible.

After many trials, he succeeded in producing the silicated borate of lead, that he employed in 1845 (as will be hereafter explained), in his researches and experiments on the magnetisation of light. Its constituents were silica, boracic acid, and oxide of lead ; and also he employed boracic acid and lead, forming a borate of lead ; but the former, or silicated borate, Faraday preferred. It has a refractive power varying from 1·8520 to 1·9135, which will be found, on referring to the preceding table of the indices of refraction for different bodies, to exceed all of them there mentioned, that could be possibly employed for any optical purpose. By reference to the *Philosophical Transactions of the Royal Society*, for the year 1830, full details of Faraday's experiments on optical and other glass may be obtained.

Double refraction differs from simple refraction in the important particular, primarily, that the ray of light incident on the refracting surface, or passing through it, is split into two parts or pencils. The phenomenon may be most readily seen by placing a piece of polished Iceland spar, or *Calcite*, as it is termed by mineralogists, on a piece of paper marked with a black spot or line ; the latter will appear double, owing to this splitting of the ray of light.

The character of this phenomenon is illustrated in the annexed cut. A ray of light is supposed to fall on a rhomb of Iceland spar. If O represent a dot on paper placed beneath the rhomb, that dot will appear doubled—namely, at O and E.

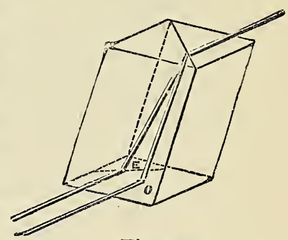


Fig. 243.

The beauty of the phenomena of polarised light (shortly to be explained), as the agent by means of which Faraday showed the magnetisation of light, greatly depends on some peculiar properties of doubly refracting bodies, especially on what is called their optical axis. Some bodies—as, for example, Iceland spar—contain but one axis ; whilst others, as nitre, &c., possess two axes of double refraction.

But we must here more particularly describe what is meant by an optic axis ; and, for this purpose, refer to the following engraving, which illustrates a rhomb of Iceland spar. If a line is supposed to be drawn from *a b* to *b c*, this would represent the axis of the mass. Let *e* be a ray of light falling perpendicularly on the surface of the rhomb. Now, if this were of glass, the ray would, according to the laws of single refraction, pass through unchanged, because perpendicularly incident thereon. But when falling on a rhomb of Iceland spar, the ray is divided into two parts, of which *e f* is the ordinary ray, and *e g* the extraordinary ray. If the ray of incident light fall obliquely, still the ordinary ray is obedient to the laws of single refraction, whilst the extraordinary pursues a course divergent from the optic axis of the crystal, and at various angles of position thereto, according to the substance under examination. In observing the two images presented by a piece of Iceland spar whilst it is turned round over a spot, it will be found that the extraordinary ray moves in a circle, whilst the ordinary remains stationary. The relation of these two rays in reference to the optic axis

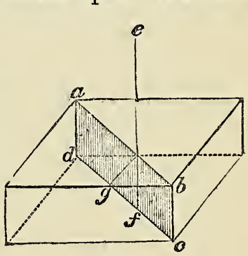


Fig. 244.

of the crystal, may thus be examined by the student, and a knowledge of their mutual divergence and position in various circumstances is at once obtained. The optic axes are respectively positive and negative when the extraordinary ray is bent either to or from the geometrical axis of the crystal. As an instance of some bodies possessing positive axes, we may mention quartz, ice, &c.; whilst Iceland spar, the tourmaline, prussiate of potass, &c., have negative axes. We shall be able to see the application of this law more fully when we enter on the consideration of polarised light, and its resulting phenomena of the production of colours, &c., under certain circumstances.

We next turn to consider the phenomena of the polarisation of light, which present some of the most astonishing and beautiful results to the eye, and, philosophically, of the highest value and importance which can be discovered in any branch of scientific research.

Polarisation is a matter of difficult definition in a popular form, and many attempts have been made to simplify it for the information of unscientific persons. Newton was the first to suggest the idea of sides, or poles, of a ray of light; and primarily, therefore, we are indebted to that eminent philosopher for the first suggestion of the polarisation of light. It may occur from either of two causes, reflection or refraction, the nature of both of which has been fully explained, or at least so far as is necessary for our purpose. Instruments employed to polarise light are termed *polariscopes*, and we shall presently describe some forms of them.

All reflecting bodies are capable of polarising light; but metals, although excellent reflectors, are, for several reasons, practically useless for the purpose. The discovery of polarisation by reflection was accidentally effected by Malus, in 1810; and the cause of that discovery introduces us to an important element of polarisation caused by reflection.

The point is, that each polarising substance has a certain angle at which the effect best takes place, and in which it must be arranged so as to reflect a polarised ray to the eye of the observer.

This angle is termed the *polarising angle;* and the following table gives the proper angle for various bodies:—

Material.	Polarising Angle.
Glass	56° 45′
Water	53 11
Quartz	56 58
Iceland spar (Calcite) . .	58 51
Sulphur	68 45
Diamond	68 1

One of the readiest means of studying the phenomena of polarised light is that afforded by two plates of the mineral called tourmaline, for all the light which passes through a plane of it is polarised. The method of using it for that purpose is—Having provided two plates of tourmaline, each mounted similarly on cork, for convenience of manipulation, let any luminous body, such as a candle, be viewed through one plate, the tourmaline being caused to revolve until a complete circle shall have been described. Next repeat the experiment, using two plates of tourmaline, laid flat together, instead of one. Provided the long axes of the tourmaline plates are coincident, both may be revolved; and the object will, in all phases of revolution of the planes, appear evident as before. No sooner are they placed at right angles to each other, however, than all the light is completely intercepted. When two polarising agents, such as these tourmaline planes, are employed in conjunction, whether in contact with each other, or some distance removed, the one nearest the eye is termed the analysing, and the one nearest the object the polarising plane, or plate. These terms will be employed hereafter in reference to another phenomenon. By means of a plane of tourmaline used as an analysing plane, it follows that the existence of polarised light may be discovered.

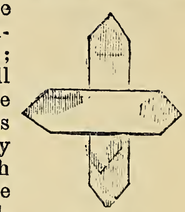
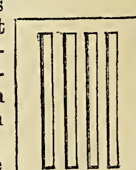


Fig. 245.

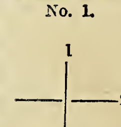
The tourmaline is the most complete polarising agent that we possess; but as it is exceedingly expensive, other arrangements, already termed polariscopes, are employed. It is, like Iceland spar, a double refracting body; that is, of itself it splits a ray of light into two parts.

In discussing the nature of so subtle an essence as light, it frequently helps the comprehension to illustrate certain phenomena in which it is involved by adopting similitudes. If, then, common or non-polarised light be assimilated to two plane agencies acting rectangularly to each other, as indicated by a rectangular cross, thus +, some consistent basis may be formed for acquiring a knowledge of polarised light in its most simple relations. We have only to assume that a ray formed of these two rectangular agencies, whilst permeating a doubly refracting crystal, gets split into two, and we immediately derive a notion of the properties of double refraction. The reason why the two rays are refracted in different planes is immediately suggested; and it only remains to frame an hypothesis accounting for the subsequent phenomena observed on viewing the two images through a plate of tourmaline.

If, in regard to this tourmaline plate, we assume it to be endowed with a transmissive property for light, as represented conventionally by the subjoined diagram (No. 1), then our first notions as to the nature of polarised light become very much extended. The reason will be now apparent why only one object, produced by a doubly refracting body, can be seen in perfection in two positions of rotation, and why each object alternately disappears. Ray No. 1 would only permeate the tourmaline, as represented in dia-



No. 1.



No. 2.

Fig. 246.

gram (1), so long as its plane might correspond with the direction of the slit-like orifices. Diagram No. 2 is equivalent to the cross just mentioned. Now if ray 1 (No. 2) can pass through the slits in diagram No. 1, it is evident that ray 2 (No. 2), being at right angles with ray 1, could not pass. Hence it would be cut off, as just explained when we described the effect of two plates of tourmaline in polarising light.

Many other illustrations have been offered, in scientific works, for the purpose of familiarising the eye and the mind of the student with these facts. Another of these is represented in the following illustration, and is but an expansion of

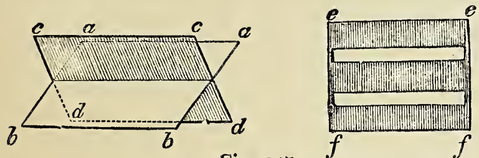


Fig. 247.

that just offered, with the advantage, however, of making the representation better understood to the eye and mind.

In Fig. 247, let *a b* represent a piece of cardboard, fixed so as to form a cross, with another piece, *c d*; and let *e f* represent a flat piece of card, through which parallel openings have been made from one side to the other. Now, supposing either end of *a b c d* be presented to *e f*, only that portion parallel to the openings of *e f* could be introduced; the other part of the cross, being at right angles to these openings, could not, of course, pass through. Thus, in a similar manner does the plate of tourmaline act on the ray of light; and in the above we have illustrated the effect observed by turning round the tourmaline plates—namely, that of the rays being alternately transmitted or extinguished. Our remarks and illustrations are, for the present, entirely confined to the consideration of what is called *plane polarised light*; or, in other words, we refer to the absorption or transmission of light, solely in connection with imaginary rectilinear planes in or about the bodies employed, for our purpose.

We have thus explained and illustrated, as near as circumstances will permit, the nature of polarisation of a ray of light; and next proceed to describe such forms of the polariscope as may be employed for the general study of the phenomena, but especially in reference to the magnetisation of light by Faraday's method.

The usual kinds of polariscope employed for the investigation of polarised light, are those that depend on reflection as a means of polarising a ray incident on a surface. These kind are easily constructed, and at the most trifling expense, a few pieces of glass being all that is requisite for the purpose.

A simple form of polariscope is seen in the following cut, in which a tube of tin or other material is shown; at each extremity of which is a piece of glass blacked at the back, and fitted at the polarising angle of about 57°. The tube is made in two parts, one fitting in the other, so that the blackened mirrors may be made to

Fig. 248.

revolve throughout an entire circle, for reasons that will be presently seen, but that have been in part explained at p. 436, *ante*, when we described the effects produced by rotating the tourmaline plates before each other.

The reflectors are fixed at each end of the tube, so as to be at an angle of 33° with its axis: it is evident, therefore, that a ray of light will fall on either at an angle of 57° (57° + 33° = 90°, the number of degrees in the fourth part of a circle). This angle of 57° is, as near as need be, an approximation, in practice, to the polarising angle of glass—56° 45′, as given at p. 436, *ante*.

If a ray of light from a candle, or daylight through a hole in a shutter, be allowed to fall on *a*, so that it shall traverse the axis of the tube, and be reflected to *b*, it will be seen by the eye at *b* when the two plates are in similar positions one to another. But if one of them be gradually turned round, the ray will as gradually diminish in intensity, and be least seen when the position of the two plates is that of being at right angles with each other. So long as the planes are parallel, the light is at its maximum intensity; and when they are at right angles, the light is of minimum intensity.

If the tube and one plate be still further turned round to a position gradually approaching to 180° of its first position in reference to the stationary mirror, it will be noticed that, gradually, the light transmitted to the eye increases in intensity; and when the revolved tube and mirror arrive at 180°, the light will regain its maximum intensity. By continuing the rotation to 270°, or 90° more, the ray will again be nearly lost; returning, however, as the mirror approaches 360°, or, in fact, its first position in reference to the other mirror or plate.

It consequently appears that, at every 90°, the rotation of the mirror affects the character of the light that reaches the eye. We find that a ray of light reflected from the surface of glass at this angle of 33°, is incapable of being reflected a second time from a similar surface perpendicular to the former, at an angle of equal incidence. It has ceased to be subject to all the ordinary laws of reflection, as before described. It is, in fact, *polarised*.

Precisely the same result, therefore, occurs by this polarisation by reflection as we noticed happens when two tourmaline plates are employed. We remarked that, at alternate angles of 90°, the light disappeared, and reappeared in the case of the tourmaline, however, by refraction, and in a more perfect manner. It is evident, therefore, as previously observed, that

the polarisation of light is equally effected by reflection and refraction.

A useful form of polariscope, invented by Biot, is represented in the following cut. It consists of two pieces of plate glass, *a b*, black-

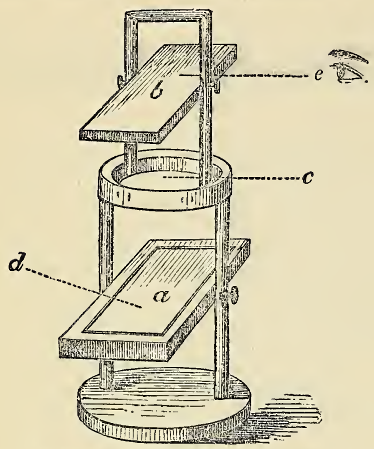


Fig. 249.—Biot's Polariscope.

ened at the back. In fact, the arrangement is, in most respects, similar to the tube arrangement that has been just described—only, in Biot's arrangement, the plates are fitted vertically in a frame; and, moreover, between the two is a stage, *c*, on which objects that are to be examined by polarised light can be placed. *a* is the polarising plate, on which a ray of light impinges at the proper angle; whilst *b* is the analysing plate, or analyser, viewed by the eye at *e*.

Those of our readers who may be desirous of a simple, cheap, and exceedingly effective instrument, may purchase Bestall's polariscope, with objects, for about 6*s*. at almost any philosophical instrument-maker's. It has the advantage of extreme simplicity, and requires no knowledge of the science for its use. Most of the gorgeous phenomena of polarised light may be viewed by it.

One extremely simple and effective instrument may be made, for a few pence, as follows:—Procure eight or ten pieces of clean window-glass, a couple of inches wide and three long. Clean them as carefully as possible; and then, laying them flat on each other, gum a piece of paper round their edges, so that they may form a compact flat bundle. Next coat the back of a piece of plate glass, a foot square, with lamp-black, or any black varnish. The bundle of glass plates will form the analyser, and the blackened glass plate the polariser.

The mode of using this arrangement is thus, and is illustrated in the following cut:—

Place the polarising plate before a window, or a candle, interposing a sheet of tissue-paper or ground glass, placed nearly perpendicularly before it, so as to give diffused light on the surface of the blackened plate. Hold the analyser in the right hand, at an angle of about 33°, with the eye looking through it. By turning the analyser through the four 90° of the circle, as already directed, the phenomenon of maximum and minimum intensity of the ray will be at once seen.

Some little care must be observed to attain the best effects. The position of each object is illustrated in the following cut; which also shows how the beautiful range and play of

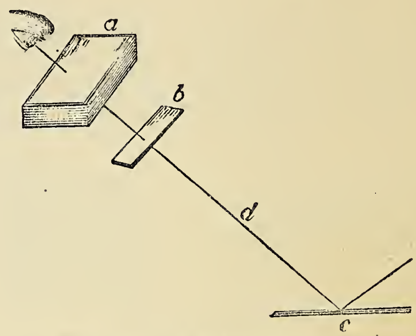


Fig. 250.—Wylde's Polariscope.

colours may be seen by such an arrangement when thin plates of mica are employed; although other substances, such as yellow prussiate of potash, &c., may be equally as successfully examined.

In the above cut, *a* represents the bundle of glass plates forming the analyser; *b* the plate of mica under examination; *c*, the polarising plate. The direction of the polarised ray is from *c* by *d* through *b*, the mica plate, the analyser, *a*, and thus at last it reaches the eye. In looking through the analyser, the long edge of the glass plates should be held as to make such an angle with the nose as that the observer may see the line of light in a plane passing about an inch from the lower end of the top surface of the analysing glass; and which, if carried through the bundle of plates, would almost touch the extremity of the under-surface of the bundle, which will thus be at an angle of about 57° with the horizon. A most beautiful play of colours may be produced by gently moving the plate of mica about in various directions. By splitting pieces of mica up into plates of different thicknesses, each piece may be made of such a size as to reflect one colour only, and its complementary (see *ante*, p. 433). A sheet of mica, therefore, presents a great number of beautiful appearances, owing to the various thicknesses of which it is composed. One of the readiest ways of splitting that substance is by making it red-hot; a great number of parallel plates are thus formed.

The above experiment illustrates, or rather introduces to, the phenomena of the display of colours arising from the interference of polarised light. Apparently to the naked eye, all transparent bodies seem alike, whether they be a piece of quartz, glass, water, or any similar substance capable of transmitting light. But when a large number of substances are submitted to the polariscope, great difference is

seen in their structure. Polarised light, in fact, gives us a means of analysis connected with, and developing to the eye, the internal structure of bodies naturally or artificially differing.

A most interesting instance of this may be tried as follows:—Instead of the piece of mica suggested in the last experiment, hold a piece of window-glass between the analyser and the polarising plate. Not the slightest appearance of colour will be noticed. Bring near to the glass a red-hot poker—immediately colours will appear, because of the unequal expansion of the glass particles. If, however, it be allowed again to cool, the glass returning to its normal state, all sign of colours vanishes. If the glass be compressed at its opposite sides by a hand-vice, or other means, so as to drive it out of shape, precisely the same result appears, so long as, by mechanical compression, it is distorted from its natural condition. It is evident, therefore, that polarised light gives us an insight into the molecular constitution of bodies, unattainable by any other means. If, in place of well-annealed glass, the unannealed be employed, the effect of colours will be noticed.

Now it will be seen, that as the analyser is turned through an angle of 90°, in all such experiments the colours observed change from the normal to the complementary. The nature of the latter has been already explained at p. 434, *ante*, and therefore need not be again dealt with. This change of colour, however, is of great beauty, and forms an interesting and characteristic property of a polarised ray of light.

Amongst the most beautiful effects that can be afforded, may be named such substances, in the form of thin plates, as mica, selenite, or crystallised sulphate of lime, the yellow prussiate of potash, and unannealed glass. If attention be paid to the directions already given, our readers may derive some of the greatest pleasures that optical science, or any other branch of experimental philosophy can afford them. Indeed, we have seen children enthusiastic in their enjoyment of the normal and complementary colours afforded by polarised light.

At a preceding page (see p. 435, *ante*) we have referred to the fact that some crystals have more than one optical axis. Those with a single axis, such as Iceland spar, &c., are termed uniaxial; whilst others, such as nitre, &c., having two axes, are termed biaxial. The latter kind of crystals afford the most beautiful effects in the polariscope; and a brief account of such results as may be obtained will be perused with interest, even by unscientific readers.

We have already noticed, at p. 438, *ante*, the rich display of colours that a plate of mica affords; but a closer examination of the phenomena of colour that it presents, adds still more to this department of optical wonder.

If a piece of mica be placed close to the analyser, and carefully examined, a proper specimen will present two black spots, round which extend five series of rings, of the most beautiful colours. These are best seen by means of a tourmaline plate; but the simple apparatus which we have described may be used.

In the centre of the rings, the black spot indicates the position of the optic axes of the mica; and besides the rings and spots, a curved line, cutting the oval rings, may be observed. The annexed engraving gives a very faint idea of the beauty of these effects; each of the curves, of course, being coloured exactly like the Newtonian rings, produced by the approximation of a lens on a flat plate of glass, as described at p. 433, *ante*, but far exceeding them in size. A similar effect is observed at both axes; and if the plate be revolved round its centre, the curved band will assume a longitudinal appearance.

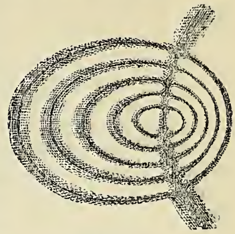


Fig. 251.

Nitre, which is also a biaxial crystal, exhibits this phenomenon in a more perfect manner, because the axes of its two crystals are close to each other. A perfect crystal is to be chosen, and a section made of it at right angles to its length, and of about the thickness of a sixth part of an inch. On this being polished, and examined in the polariscope, the appearances presented are exceedingly beautiful. The two axes, rings, &c., are nearer together than in the case of mica; and their appearance is represented in the annexed engraving, together with a cross, which extends between the two axes. The cross may be made to assume various positions, by causing the piece of nitre to revolve between the analyser and the polariser, on the geometrical axis of the crystal. Particular attention is required to the polish, thickness, and other points. This, and many other crystals, however, may be purchased, ready mounted, of the opticians. Amongst such, we may mention Iceland spar, which presents a very fine appearance when of proper thickness.

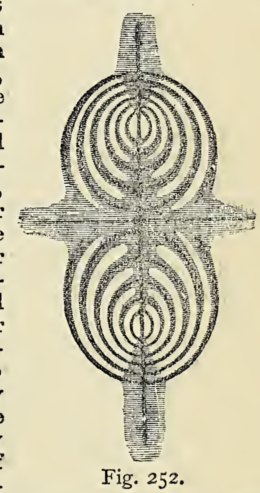


Fig. 252.

Many other crystallised bodies, such as the topaz, sulphate of nickel, carbonate of soda, &c., present a double system of rings, such as have been illustrated. The curves are crossed by two bands, the position of which, in reference to the eye of the observer, depends on the position of the analyser.

A Nichol's prism, or eye-piece, is of great use in experiments on the polarisation of light. It is made by cutting a rhomb of Iceland spar, and cementing the opposite sides by Canada balsam, in a wedge-like form. It has the advantage of separating, as far as possible, the ordinary from

the extraordinary ray; hence, in many forms of the polariscope to be noticed, especially in Faraday's experiments, it is of great value. This is of especial importance in circular polarisation, now to be explained; and, as we shall subsequently see, the phenomena of the magnetisation of light is one of rotation in respect to optical, magnetical, and electrical lines of force.

In respect to circular polarisation, it may be remarked, that it greatly differs, in numerous respects, from plane polarisation, already described.

Many specimens of rock crystal may be selected, which, if properly divided, and the section placed between the polarising and analysing plates of any of the forms of the polariscope already described, do not yield the alternating black and white central spot and radiating cross; but instead of this, the central spot is illuminated by colours, that change through all those presented by the prism when the plate of quartz is caused to revolve on its own axis. In some specimens of that mineral, rotation of the plate on its own axis from right to left, causes the colours to appear in the order of red, yellow, blue; whereas, in other specimens of quartz, this order of alternation occurs when the quartz is turned in an opposite direction. Hence there is right-handed quartz (the former), and left-handed quartz (the latter). This quality of circular polarisation is another agent of chemical analysis. On first contemplation, it might be supposed to be connected with the solid molecular condition of the crystal; but this is not so—the property of circular polarisation being also exhibited by certain liquids.

The subject of circular polarisation is one strikingly illustrative of the way in which a subject, apparently altogether abstract and recondite, may be applied to the most practical ends. Two remarkable examples of this application we shall mention—the first relating to a method of indicating the progressive change during fermentation of starch into glucose or grape sugar; the second relating to a method of distinguishing between the latter in glucose and sugar of the cane.

When infusion of malt is mixed with yeast, and exposed to the proper fermentative temperature, a gradual change takes place of starch; and a modification of starch, called dextrine, into the glucose or sugar of grapes, to which the sweetness of the wort is due. Now, solutions of starch and dextrine, and grape sugar, all possess the property of circular polarisation; but with this difference—the two former polarise towards the right (whence the name dextrine is derived); the latter polarises towards the left. Hence, by placing an infusion of malt, at progressive stages of fermentation, in a tube of definite length, connected with a polarising apparatus, and reading off the amount of right-handedness or left-handedness displayed by the solution, the progressive changes of starch and dextrine towards grape sugar or glucose may be made evident.

Still more important is the application of this principle to the discrimination of cane and grape sugars. Slightly entering on the subject of organic chemistry, it must be here premised that the terms glucose or grape sugar are not specific, but generic; they are not limited to the indication of sugar which is contained in the grape, but extend to the comprehension of all sugar, from whatever source, having an identical composition. In like manner, by the term cane sugar we understand a sugar, from whatever source derived, that has a composition of the saccharine crystals extracted from sugar-cane.

Cane sugar is that alone which possesses any value as a manufactured article—the only kind which admits of crystallisation or formation into loaves. Yet cane sugar rapidly, under certain circumstances, changes into grape sugar; and as both yield a solution, sweet, colourless, and probably of equal specific gravities, the value of a process for determining the presence and the proximate amount of either becomes of the highest importance. By taking advantage of the fact that cane sugar polarises circularly towards the right, grape sugar towards the left, the necessary information can be obtained.

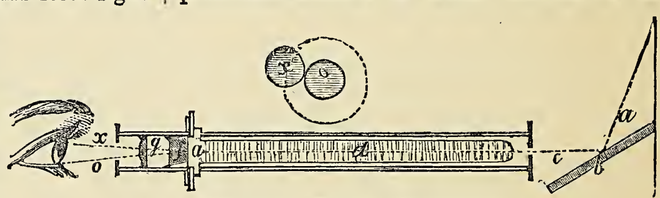


Fig. 253.—Circular Polarisation.

The method, whilst being perfectly satisfactory in its results, saves a vast amount of trouble to the experimental chemist, and also in various manufactures in which sugar is operated on; the trouble of qualitative and quantitative analysis becoming unnecessary.

M. Biot has contrived an optical instrument for this specific purpose. Its form is represented by the above engraving.

A ray of common light having been polarised by reflection at the angle 56° 45′ from the surface, *b*, of a plate of glass, the plane polarised ray, *c*, obtained by this means, is first made to pass through a lens, *g*, to give distinctness of image, and then through a pure solution of crystallisable cane sugar, *d*: the emergent ray, *e*, being now analysed by a double refracting rhomb of calcareous spar, *f*, two coloured images are perceived; one, *o*, caused by ordinary, the other, *x*, by extraordinary refraction. The colours of the two images are complementary; that is, when one image is red, yellow, or blue, the other image is green, violet, or orange. If, now, the analysing rhomb of calcareous spar be rotated, change of colour is effected. If the rotation be right-handed—*i.e.*, in the direction of turning an ordinary screw—the colours follow each other in the order of red, orange, yellow, green, blue, indigo, and violet; meantime, the extraordinary image assumes a series of comple-

mentary tints. But the chromatic relation of the two images may be most readily perceived by the following comparative arrangement :—

Ordinary Image.	Extraordinary Image.
Red	Green
Orange	Blue
Yellow	Indigo
Green	Violet
Blue	Red
Indigo	Orange
Violet	Yellow
Red	Green

Another form of apparatus for studying the same phenomena is represented in the following cut. *a* represents a Nichol's prism, or eye-piece, fixed, by means of a ring and screw, on a common laboratory ring-stand ; *b* is a tube, in which the liquid to be examined is placed, and it may be conveniently coated with black paper to keep out all extraneous rays. These tubes must be of various lengths, to suit the different liquids which may be employed ; and they are held upright between the eye-piece and the polariser, by means of a ring, which is again attached, by the screw, *c*, to the ring-stand : *d* is an ordinary polarising plate, attached to the stand by the screw, *e* ; and *f* is the eye of the observer. We need scarcely state, that the analyser must so rest in its socket as to be readily turned round through the circular ring, as by means of its rotation over the tube, *b*, the phenomena are observed.

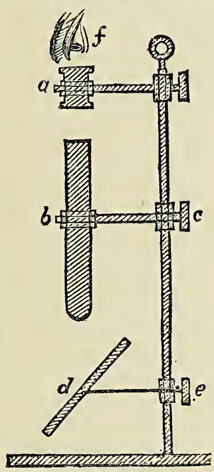


Fig. 254.

In complete instruments, *a* rests in a graduated frame, which is essential for accurate experiments, because the angle of rotation varies for each liquid examined ; and their differences, with respect to polarised light, are so pointed out. The bottom of the tube, *b*, should be as flat as possible, so as to prevent the loss of light on account of its external curvature.

Either of the apparatus thus described is capable, with modifications to be hereafter pointed out, of exhibiting the phenomena of the magnetisation of light in the experiments suggested by Faraday.

We may just shortly point out the essential difference which exists between plane and circular polarisation. In the former, the chief effects are witnessed when the planes of observation are at *right* angles to each other. In circular polarisation these angles vary, and depend on circumstances, which, in their turn, arise directly from the peculiar or individual constitution of the body under examination. We should remark, that the best plan of observing the phenomena of circular polarisation, is that of using homogeneous or single-coloured light ; and this is easily managed by interposing a plate of red glass between the eye and the analysing prism. This prevents a variety of disturbing causes ; and it also ensures the disappearance of the extraordinary ray.

Some little difficulty occurs to the beginner in observing the direction of rotation ; because, as we have just stated, different liquids require greater lengths before the phenomenon is exhibited. The following, however, we may adduce respectively, as instances in which the effects may be observed ; and, as they have all been tried in an equal length of tube—namely, in one of about six inches—they will afford a starting-point from which to commence progress. We have also given the angle, as indicated by the index on the analyser, which completes the arc of rotation for each.

Possessing Left-handed Polarisation.

Oil of turpentine	45°
Naphtha	12° 40′

Possessing Right-handed Polarisation.

Oil of bergamot	29°
Weak solution of cane sugar in water	23° 5′
,, ,, of milk ,, ,, ,,	10° 3′

It will be thus observed, that the angle of the arc of rotation, and its direction, become definite physical characteristics of the various bodies in solution to which we may apply the test of polarised light. These researches have been of the greatest advantage to the chemist as a means of analysis ; and, as such, we cannot too highly value the results which have been obtained.

We have been compelled thus to give a very extended notice of some of the leading phenomena of light, because, as our work is intended for those unversed as well as those versed in scientific matters, the former class would be utterly incapable, without such introductory remarks, of understanding or appreciating the nature and value of the discoveries that Faraday made when he found out that light is affected by magnetic and electric forces. It is impossible, in the limits of this volume, to enter into every detail of the numerous interesting points of philosophical study that have been, or may be, suggested by the facts of the subject. Indeed, the constant daily progress of scientific research makes it impossible to do more than glance at the results constantly accumulated. Even so recently as a quarter of a century ago, a carefully educated scientific man could, without great difficulty, enter on an examination of nearly every branch of natural or experimental philosophy and chemistry. But Faraday, Brewster, and their contemporaries, have so increased the landmarks of our knowledge, that even a branch of science requires to be sub-divided, in its study, to be competently examined and understood. If similar progress be made in another quarter of a century, there must be mental giants in those days to master even details. As Newton justly observed, the vast ocean of truth is ever before us, unexplored ; and, on account

of our finite intelligence, must ever remain so. Beautiful were the almost dying words of the late Sir David Brewster. Sir James Simpson remarked, that, shortly before his death, "I said to him, that it had been given to him to show forth much of God's great and marvellous works; and he answered—'Yes, I have found them to be great and marvellous, and I have felt them to be His.'" Such words express, in their simplicity, that whatever our powers may be, they are simply mere shadows to those of the Creator; hence, what at one time may be considered as an important addition to our knowledge, becomes eventually eclipsed by a further glimpse into creation, by which all our previously-attained knowledge is either confounded or rendered futile.

With these introductory observations we now proceed to inquire into Faraday's great discovery of dia-magnetism, and the various consequences that have resulted therefrom in respect to our knowledge of the causes of many natural phenomena, and the theories that have been adduced for their explication.

Magnetisation of Light.

Faraday introduces, in Series XIX. of "Electrical Researches," his first attempts at investigating the action of magnetism on a ray of light. The paper was read before the Royal Society on November 20, 1845; and was entitled, *On the Magnetisation of Light, and the Illumination of Magnetic Lines of Force;* and he divided it into three paragraphs or sections. 1st. *The Action of Magnets on Light.* 2nd. *The Action of Electric Currents on Light.* 3rd. *General Considerations*—of course arising from the results he had arrived at.

With his usual caution, however, Faraday did not commit himself to any received theory of light; and remarks—"The title of this paper* has, I understand, led many to a misapprehension of its contents, and I therefore take the liberty of appending this explanatory note. Neither accepting nor rejecting the hypothesis of an ether, or the corpuscular, or any other view that may be entertained of the nature of light; and, as far as I can see, nothing being really known of a ray of light more than that of a line of magnetic or electric force, or even of a line of gravitating force, except as it and they are manifested in and by substances—I believe that, in the experiments I describe in this paper, light has been magnetically affected, and, in turn, has affected that which is truly affected in the force of light. By the term *magnetic*, I include here either of the peculiar exertions of the power of the magnet, whether it be that which is manifest in the magnetic or the dia-magnetic class of bodies. The phrase 'illuminations of the lines of magnetic force,' has been understood to imply that I had rendered them luminous. This was not within my thought: I intended to express, that the line of magnetic force was illuminated as the earth is illuminated by the sun, or the spider's web [of the micrometer] illuminated by the astronomer's lamp. Employing a ray of light, we can tell, *by the eye*, the direction of the magnetic lines through a body; and, by the alteration of the ray, and its optical effect on the eye, can see the course of a thread of glass, or any other transparent substance, rendered visible by the light; and this is what I mean by 'illumination.'"

Having thus, by means of these explanatory remarks, explained the limits that Faraday placed on his early results, we next, by making extracts from, and observations on, this paper, illustrate his early success in magnetising a ray of light.

The paper commences as follows:—

"I have long held an opinion, almost amounting to conviction, in common I believe with many other lovers of natural knowledge, that the various forms under which the forces of matter are made manifest have one common origin; or, in other words, are so directly related, and naturally dependent, that they are convertible, as it were, one into another, and possess equivalents of power in their action. In modern times, the proofs of their convertibility have been accumulated to a very considerable extent, and a commencement made of the determination of their equivalent forces.†

"This strong persuasion extended to the power of light, and led, on a former occasion, to many exertions, having for their object the discovery of the direct relation of light and electricity, and their mutual action on bodies subject jointly to their power; but the results were negative, and were afterwards confirmed in that respect by Wartmann."

Here it must be explained, that, in 1834, Faraday had attempted to analyse the tensive effect of a voltaic current producing electrolysis, by transmitting a ray of polarised light directly across the course of the electric current in a liquid undergoing decomposition; but he then found "not the slightest action on the ray could be perceived." (Series VIII., § 951, 952.) In § 955, in the same series, he states his attempts to produce the hoped-for effects with borate of lead, glass; but no positive result was arrived at then, in any way indicating the mutual effects of light and electricity.

Resuming our extracts from the papers of 1845, he continues:—

"These ineffectual exertions, and many others which were never published, could not remove my strong persuasion, derived from philosophical considerations; and therefore I recently resumed the inquiry, by experiment, in a more strict and searching manner, and have at last succeeded *in magnetising and electrifying a ray of light, and in illuminating a magnetic line of force.*"

Faraday next defines some terms he employs, and that have been already alluded to. By *line of magnetic force*, or *magnetic line of force*, he means that exercise of magnetic force which is exerted in the lines usually called magnetic

* Vol. iii., p. 1. *Experimental Researches;* in the footnote.

† See introductory remarks at the commencement of this chapter, p. 428, *ante*.

curves,* and which equally exist in passing from or to magnetic poles, or forming concentric circles round an electric current.† By *line of electric* force, he meant the force exerted in the lines joining two bodies, acting on each other according to the principles of static-electric induction, and that may either be curved or straight lines.

He also defines the term *dia-magnetic* as a body through which lines of magnetic force are passing, and which do not, by their action, assume the usual magnetic state of iron or the loadstone.

Here it may be well to impress the distinction between magnetic and dia-magnetic bodies. Magnetic bodies, such as iron, steel, nickel, and cobalt, are capable of exhibiting such phenomena as attraction, repulsion, and polarity, arising from magnetic induction—as seen in the needle of the mariner's compass, the bar, horseshoe, and electro-magnet. A dia-magnetic body is not so characterised. Amongst metals, bismuth was found to be the most *dia-magnetic*, although not having in the least degree the magnetic character of iron. Generally, the terms *magnetic* and *dia-magnetic* may be defined as expressing the opposite characteristics of bodies in reference to the passage of lines of magnetic force; but this will be better understood when we enter into the full description of dia-magnetism.

Faraday's first successful result was obtained in the following manner, as described in his own words. It may first be stated that he employed, as a dia-magnetic, heavy glass, composed of borate of lead and silica, which he discovered during his researches into the nature of glass in 1830, and which he termed silicated borate of lead. It has a high refractive power, and was the most suitable material that Faraday was then acquainted with for investigating the mutual action of light and magnetism. He continues :—

"A ray of light issuing from an Argand lamp was polarised [see *ante*, p. 436] by reflection from a surface of glass, and the polarised ray passed through a Nichol's eye-piece [see *ante*, p. 439], revolving on a horizontal axis, so as to be easily examined by the latter. Between the polarising mirror and the eye-piece, two powerful electro-magnetic poles were arranged, being either the poles of a horse-shoe magnet, or the contrary poles of two cylindrical magnets. They were separated from each other about two inches, in the direction of the line of ray, and so placed, that if on the same side of the polarised ray, it might pass near them; or, if on contrary sides, it might go between them, its direction being always parallel, or nearly so, to the magnetic lines of force. After that, any transparent substance placed between the two poles would have, passing through it, both the polarised ray and the magnetic lines of force at the same time and in the same direction.

"A piece of the silicated glass, about two inches square, and 0·5 [half] of an inch thick, having flat and polished edges, was placed as a dia-magnetic between the poles (not as yet magnetised by the electric current), so that the polarised ray should pass through its length; the glass acted as air, water, or any other indifferent [but, we must add, transparent] substance would do; and if the eye-piece were previously turned into such a position that the polarised ray was extinguished, or rather the image produced by it rendered invisible, then the introduction of this glass made no alteration in that respect. In this state of circumstances, the force of the electro-magnet was developed by sending an electric current through its coils, and immediately the image of the lamp-flame became visible, and continued so as long as the arrangement continued magnetic. On stopping the electric current, and so causing the magnetic force to cease, the light instantly disappeared. These phenomena could be renewed at pleasure, at any instant of time, and upon any occasion, showing a perfect dependence [or connection] of cause and effect.

"The character of the force thus impressed upon the dia-magnetic is that of *rotation;* for when the image of the lamp-flame has thus been rendered visible, revolution of the eye-piece right or left, more or less, will cause its extinction; and the further motion of the eye-piece to the one side or other of this position, will produce the reappearance of the light, and that with complementary tints, according as this further motion is to the right or left hand.

"Magnetic lines, then, in passing through silicated borate of lead, and a great many other substances [which will be fully described hereafter], cause these bodies to act upon a polarised ray of light when the lines are parallel to the ray, or in proportion as they are parallel to it. If they are perpendicular to the ray, they have no action upon it. They give the dia-magnetic the power of rotating the ray; and the *law* of this action on light, is that if a magnetic line of force be *going from* a north pole, or *coming from* a south pole, along the path of a polarised ray coming to the observer, it will rotate that ray to the right hand. Or that, if such a line of force be coming from a north pole, or going from a south pole, it will rotate such a ray to the left hand."

After thus expressing the chief points of the newly-discovered phenomena, and enunciating the law of action, Faraday, in his usual lucid manner, furnishes us with simple means of studying them.

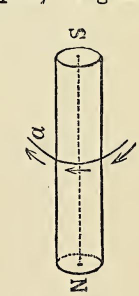


Fig. 255.

"If a cork, or a cylinder of glass, representing the dia-magnetic [see Fig. 255], be marked at its ends with the letter N and S, to represent the poles of a magnet, the line [dotted in the cut] may be considered as a magnetic line of

* See article on *Magnetism* generally; but especially our remarks on the subject of magnetic curves.

† See article *Electro-Magnetism*, in reference to mutual rotation of magnets, and electrified wires, &c.

force. And further, if a line be traced round the cylinder with arrow-heads, *a*, on it to represent direction, such a simple model, held up before the eye, will express the whole of the law, and give every position and consequence of direction resulting from it. If a watch be considered as a dia-magnetic, the north pole of a magnet being imagined against the face, and a south pole against the back, then the motion of the hand will indicate the direction of rotation which a ray of light undergoes by magnetisation."

In such simple terms does Faraday express the results he obtained in a discovery that, in a philosophical point of view, has scarcely ever been excelled in interest. What Newton did for us in regard to masses and the exterior, if we may so say of matter, Faraday has effected in respect to the internal forces of nature. Newton we may consider to have successfully used Nature's telescope: whilst to Faraday was left the equally important and interesting use of Nature's microscope. The one penetrated the arcana of the heavens, in the mutual relations of the immense planetary bodies and their common centre; whilst the other studied the mutual action of the molecules of matter, with an equal, if not greater, success. At first sight, it would appear that their pursuits were entirely of an opposite character. But such was not the case. Faraday, by his electrical and magnetical discoveries, filled up a void of two centuries: and, as he hinted (see p. 442, *ante*), electricity, magnetism, and gravitation might be the same. The result of his investigation all but proved such to be the case: but this is a subject on which we shall have hereafter to enlarge more fully, when we investigate the relation or connection that subsists between all the forces of nature.

To the unscientific reader, who has been accustomed to consider magnetism as a special affection of some form of iron, as hard, cast, or in the shape of steel, it would seem an extraordinary thing to prove that all bodies are subject to the force. This, however, will be subsequently shown to be the case: but before proceeding to this expansion of our subject, we may suggest a comparatively simple arrangement, by means of which, the magnetisation of a ray of light may be, with a little care, readily effected.

At a preceding page, when treating on electro-magnetism, it was stated, that if about 100 feet or yards of copper wire were coated with silk or cotton, and wound, helix form, on a hollow cylinder of wood, the two extremities of the coil being connected with any modern form of a voltaic cell, the current of electricity so passed by the wire of the coil, would instantly convert a piece of soft iron into a magnet; and that the magnetic characteristics would continue so long as the current passes round the soft iron. Now by a modification of the simple horizontal polariscope (illustrated at p. 440, Fig. 253, *ante*), that we described might be used to study circular polarisation, the magnetisation of a ray of polarised light can be effected. Thus, if such a polariscope be placed, so far as the glass tube is concerned, inside a coil similar to that just described, and in place of the iron rod, it is evident that when a current of electricity, say from six cells of a Grove's, Bunsen's, or Callan's battery, be sent through the coil, the tube in the axis will be subject to the influence of the magnetic force so induced. Consequently, a ray of light, passing from the polarising plate to the analyser, will be in precisely the same position, physically, as the bar of iron in the electro-magnet. and will be subjected to magnetisation.

Fig. 256 illustrates such an apparatus; *a a a a* is supposed to be a coil of copper wire, wound

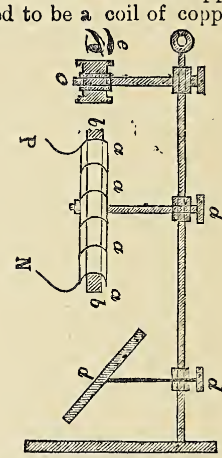


Fig. 256.—Magnetising Light.

round a hollow bobbin, eight inches long, which encloses a thin iron tube or core; *b b* is a glass tube, filled with the dia-magnetic, which may be oil of turpentine; P N are the two extremities of the wire coil, to be placed, when the experiment is conducted, in contact with terminals of the voltaic battery; *c* represents Nichol's prism, or eye-piece, forming the analyser, and the plate *d* the polariser (by polarisation by simple reflection, as explained at page 437, *ante*), and *e* represents the eye of the observer. A ray of light from the polariser passing through the Nichol's prism, will reach the eye, *e*, in a polarised condition, presuming for the moment that the coil, *a a*, is not the subject of voltaic action. If P N be then connected with a voltaic battery, of the power just named, the current circulating round it will magnetise the enclosed cylinder of iron, and simultaneously magnetise the polarised ray. If, in the first instance, the appearance of the ray to the eye of the spectator was that of darkness, the instant the current converts the iron into a magnet the dark spot will disappear, just as if the analyser had been turned through a quarter of a circle (see *ante*, p. 438). The appearance will last so long as the current circulates in one direction. But if that be reversed so that the current shall pass in an opposite direction through the coil, the appearance of the polarised ray will be changed. In fact, and in a few words (as already described by Faraday at p. 442, *ante*), the induced magnetism has a direct action on the polarised ray, just as would be effected by the rotation of

the analyser in the ordinary way; and, consequently, if a coloured image were perceived in the first instance, the change of the direction of the current would have the effect of presenting a complementary colour, in the manner already fully described at p. 441, as effected by rotation in any form of the polariscope.

In this case, for instance, the oil of turpentine takes the place of the heavy glass used by Faraday as a dia-magnetic. He states that its natural rotating force is nearly double that of heavy glass, or more exactly, as 11·8 to 6; water being reckoned as the standard, or 1. On this point Faraday remarks (*Exp. Res.*, Series XIX., § 2,215)—"For the sake of supplying a general indication of the amount of induced rotating force in two or three bodies, and without any pretence of offering correct numbers, I give generally the results of a few attempts to measure the force, and compare it with the natural power of a specimen of oil of turpentine. A very powerful electro-magnet was employed, with a *constant* distance between its poles of 2½ inches [see description of apparatus employed by Faraday, given at p. 443, *ante*]. In this space were placed different substances, the amount of rotation of the eye-piece observed several times, and the average taken, as expressing the rotation for the ray-length of substance used. But as the substances were of different dimensions, the ray-lengths were, by calculation, corrected to one standard length, upon the assumption that the power was proportionate to the length."

On this point, in a preceding section, Faraday had arrived at the conclusion that "the rotation appears to be in proportion to the extent of the dia-magnetic, through which the ray and magnetic lines [of force] pass. I preserved the strength of the magnet and the interval between its poles constant, and then interposed different pieces of the same heavy glass between the poles. The greater the extent of the dia-magnetic in the line of ray, whether in one, two, or three pieces, the greater was the rotation of the ray; and as far as I could judge by these first experiments, the amount of rotation was exactly proportional to the extent of the dia-magnetic through which the ray passed. No addition or diminution of the heavy glass on the *side* of the course of the ray made any difference in the effect of that part through which the ray passed."

Having thus proceeded on the assumption that the length of the dia-magnetic affects the rotation of the ray, we return to the conclusion of his remarks in § 2,215. He adds:—"The oil of turpentine was, of course, observed in its natural state; *i. e.*, without magnetic action. Making water = 1, the numbers were as follow:—

Oil of turpentine . . .	11·8
Heavy glass	6·0
Flint glass	2·8
Rock salt	2·2
Water	1·0
Alcohol.	less than water.
Ether	less than alcohol."

He also found that the power of rotating the ray *increased* with the intensity of the magnetic line of force. "This general effect is very easily ascertained by the use of electro-magnets; and within such range of power as I have employed, it appears to be directly proportionate to the intensity of the magnetic force." Iron he found to affect the results; but ordinarily non-magnetic metals, such as copper, lead, tin, silver, &c., produced no effect on the phenomena.

Faraday tried, as dia-magnetics, a large range of solids or fluids, and observed varying effects to arise therefrom. He found in all cases that they were subject to the general law enunciated at p. 443, *ante*, and illustrated by a diagram, in which the direction of the magnetic line of force through a dia-magnetic cylinder is shown by dotted lines; whilst that of the rotation of a ray of light is indicated by an arrow.

The second paragraph of Series XIX., § 2,189, *et seq.*, is devoted by Faraday to the consideration of the *Action of Electric Currents on Light.* He commences inductively by remarking—"From a consideration of the nature and position of the lines of magnetic and electric force, and the relation of a magnet to a current of electricity, it appeared almost certain that an electric current would give the same result of action on light as a magnet; and in the helix would supply a form of apparatus, in which great lengths of dia-magnetics, and especially of such bodies as appeared to be but little affected between the poles of the magnet, might be submitted to examination, and their effect exalted: this expectation was by experiment realised."

The apparatus already illustrated by the preceding engraving, represents the helix method, that was a great improvement on Faraday's early plan; for, as he here states, greater lengths of dia-magnetics could be employed than by the method he first used. In the one we just described, however, it will be noticed that a thin iron core or tube should be inserted within the coil, and inside which is placed the dia-magnetic. Of course the iron core becomes powerfully magnetic, and produces magnetic affection on the ray of polarised light. In the present inquiry, in respect to the action of electric currents on light, of course an iron core was not employed, but simply the ordinary helix of covered copper wire. This arrangement is necessary to prove the absolute action of electric currents on light; although Faraday stated, that even if the liquids employed were inserted in the helix in an iron tube, still the influence of electric currents on a ray of polarised light was the same, and not in the least affected.

He used helices of different lengths, and discovered that, as in magnetisation of light, so in its electrisation, the *length* of the dia-magnetic influenced the result—the greater the length, the higher was the intensity of effect. (See his remarks on this point in relation to magnetisation, given above.) The results he obtained generally, in respect to the influence of electricity on light, he remarks on as follows (§ 2,199, 2,200)—"The LAW by which an electric current

acts on a ray of light is easily expressed. When an electric current passes round a ray of polarised light in a plane perpendicular to the ray, it causes the ray to revolve on its own axis, as long as it is under the influence of the current, in the *same direction* as that in which the current is passing.

"The simplicity of this law, and its identity with that given before, as expressing the action of magnetism on light, is very beautiful. A model is not wanted to assist the memory; but if that already described [see p. 443, Fig. 255] be looked at, the line round it will express at the same time the direction both of the current and the rotation. It will, indeed, do much more; for if the cylinder be considered as a piece of iron, and not a piece of glass or other dia-magnetic, placed between the two poles, N and S, then the line round it will represent the direction of the currents, which, according to Ampère's theory, are moving round its particles; or, if it be considered as a core of iron [in place of a core of water], having an electric current running round it in the direction of the line, it will also represent such a magnet as would be formed if it were placed between the poles whose marks are affixed to its ends."

Faraday also discovered, that in cases of bodies being introduced into the helix that possess a naturally rotating force (see our introductory remarks on *circular polarisation* of sugar, &c., at p. 440, *ante*), then the rotating power given by the electric current is superinduced upon them exactly as in the case of magnetism; that is, the effect both of the electric and magnetic action is, to increase or decrease their specific force according as the natural rotation; and that induced by magnetism or electricity is right or left-handed.

Faraday concludes Series XIX.—to an analysis of which the preceding pages are devoted—with certain general considerations.

The most important point of these considerations is, perhaps, that in which he explains the connection between the dia-magnetic phenomena and matter. He remarks (§ 2,224) that the magnetic forces do not act on the ray of light directly, and *without the intervention of matter*, but through the mediation of the substance in which they and the ray have a simultaneous existence; the substances and the forces giving to, and receiving from, each other the power of acting on light. This is shown by the non-action of a vacuum, of air and gases; and it is also further shown by the special degree in which different matters possess the property. That magnetic force acts upon the ray of light always with the same character of manner, and in the same direction, independent of the different varieties of substances, or their states of solid or liquid, or their specific rotative force, shows that the magnetic force and the light have a direct relation; but that substances are necessary, and that these act in different degrees, show that the magnetism and the light act on each other through the intervention of matter.

Faraday anticipates, prophetically, another of his great discoveries, which is simply, as we shall hereafter see, an expansion of dia-magnetic phenomena in the universal obedience of bodies, solid, liquid, and gaseous, to magnetism; for in § 2,226, he remarks that it cannot be doubted that the magnetic forces act upon and affect the internal constitution of the dia-magnetic, just as freely in the dark as when a ray of light is passing through it; though the phenomena produced by light seem as yet to present the only means of observing this constitution and the change. Further, any such change as this must belong to opaque bodies, such as wood, stone, and metal; for, as dia-magnetics, there is no distinction between them and those which are transparent. The degree of transparency can, at the utmost, in this respect, only make a distinction between the individuals of a class.

In *Comptes Rendus*, 1846, a method of showing the direct relation of light and magnetic force in connection with matter, as suggested by Faraday, will be found. We are indebted for an outline of the method to Dr. Noad, slightly modified to suit our present purpose.

Place, side by side, a certain quantity of water in a helix, and a tube containing oil of turpentine. If the oil possess a right-hand rotation, pass an electric current through the helix, so as to give rotation to the right; the water in the tube will acquire a rotatory power to the right, and the two liquids will possess the same mode of action. Leaving now the tubes, the helix, and the current in the state just described, pass the polarised ray in the contrary direction through the tubes, and observe at the opposite extremity of the tube. The oil of turpentine will be seen to turn the ray to the right; but it will not be the same with the *water*, which will turn the ray to the left; the rotation being absolutely connected with the direction of the electric current, which moves in the circuit, and which, seen through this extremity, passes to the left. If, instead of water, oil of turpentine be in the helix, and if the electric current be sufficiently intense to produce, on the luminous ray, a rotation equal to that determined by the oil, its rotatory power on a ray passing in a certain direction will appear double; while, examined by a ray passing in the contrary direction, it will be reduced to zero. This fact is additional proof of what Faraday states—that it is only by the intervention of matter that the relations of light with electricity and magnetism can be made manifest, and that different substances equally affect the result.

Several years after Faraday thus gave to the world glimpses of this great discovery, other modes of showing the affections of magnetism and light became known. Rhumkorff's, and any other induction coils, show this effect well; for the luminous flame produced in a vacuum may be attracted, &c., by a magnet with perfect ease. The electric light from a powerful voltaic arrangement, as produced from charcoal points, can also be made to revolve around the pole of a permanent magnet in opposite directions, according to which pole of the magnet is presented to it, or rather within it, or to the direc-

tion of the current. But, in both of these cases, we are more correct in stating that *luminous matter* so revolves. Faraday's early results were obtained, as we have pointed out, only by means of *polarised light*; and in the concluding section but one (§ 2,241) of the Series (XIX.) that we have hitherto alone dealt with, he remarks—"Although the magnetic and electric forces *appear* to exert no power on the ordinary, or on the depolarised ray of light, we can hardly doubt but that they have some special influence, which, probably, *will soon be made apparent by experiment.* Neither can it be supposed otherwise than that the same kind of action should take place on the other forms of radiant agents, as heat and chemical force." In the concluding paragraph, he sagaciously suggests that the then imperfect glimpse which he had gained of the mutual action of light, magnetism, and electricity, might gain cosmical importance. "What the possible effect of the force may be in the earth, as a whole, or in magnets, or in relation to the sun; and what may be the best means of causing light to evolve electricity and magnetism, are thoughts continually pressing on the mind: but it will be better to occupy both time and thought, aided by experiment, in the investigation and development of real truth, than to use them in the invention of suppositions, which may or may not be founded on, or consistent with, fact."

Two great traits of Faraday, *as a man*, were his modesty and his simplicity; two of them, *as a philosopher*, were the accuracy of his deductions, and the sagacity of his predictions. The last sentence that we have quoted pre-eminently shows all these qualifications as possessed by him. His sagacity was especially evinced in his actually predicting, in the sentence, that which has since been proved to exist—that is, a connection between solar light with terrestrial magnetism and electricity; whilst, with his persistent pursuit of rigid induction on fact alone, we perceive, at the same time, that accuracy of object in research that never led him to theorise beyond limits of absolutely known fact, data, or experiment.

We next turn to the discoveries which Faraday made in respect to the dia-magnetic qualities of bodies of all kinds—a subject which introduces us to the fact that magnetism is a universal affection of matter.

By slow degrees Newton arrived at the conclusion that matter acts on matter, in proportion to the mass of each. Proceeding on that supposition or exposition of the laws of gravitative force, we have been enabled to weigh the stars (planets) as in a balance; assign their position, under all ordinary circumstances, with such exactness that a navigator observing them can tell in what part of the world he may be, with an error of less than a mile, although he may be thousands of miles away from land; predict future eclipses to such an extent of precision that the actual error shall be less than a second of time; find out a planet that had never been previously seen, and tell the exact place where it ought to be, and was discovered; and, in fact, generally to predicate and describe astronomical phenomena with a precision that would almost suggest the quality of omniscience as a possession of mankind.

But our success in these respects results from the universality of the law of gravitation. The earth attracts the apple to its centre; the earth equally attracts the moon; or, as a common centre of attraction, the sun acts on Mercury, Venus, the earth and its moon, Mars, and the remaining members of our planetary system. Hence we notice, that without the least regard to the chemical, physical, or other conditions of such planets, the action of gravitation is identical on them in every case.

Now, before the discoveries of Faraday that we are dealing with, magnetism was not in the category of such universality. As already pointed out, iron, cast, soft, or in the form of steel, and, still more limited, cobalt and nickel, were considered as the only bodies susceptible of magnetic influence. As we shall presently see, Faraday has proved that every substance known to man is subject to that influence; and the fact that a man himself may be with certainty affected by the magnet, equally so, but in an opposite character, with the magnetic needle of the mariner's compass. It will be shown that whilst the latter tends to a polarity of nearly north and south, the man would, under magnetic influence, point nearly east and west.

The greatness of Faraday's discovery of dia-magnetism, therefore, essentially consists in its proving the *universality* of the influence of the magnetic force. Newton *began* his proofs of the laws of the attraction of gravitation with the earth, and *ended* them in their application to every part of the universe. Faraday *began* with the then known (1845) laws of magnetism, as affecting iron, cobalt, and nickel, and *ended* by showing that *all matter*, solid, liquid, and gaseous, and even light itself, is subject to magnetic influence.

The phenomena of dia-magnetism, in respect to the affection of light by magnetism, having been disposed of, we now, therefore, turn to the magnetic condition of matter generally. The relations of matter and magnetism, in reference to the poles of a magnet, must, however, be first defined with the terms that Faraday employed to designate them; for by the latter much circumlocution will be saved.

In the following cut, N and S represent the poles of a magnet, of the horse-shoe or any other form; but, preferably, of a horse-shoe electro-magnet. The interval between N and S is termed the magnetic field. It is that position in which the greatest amount of magnetic force is evidenced. A line, stretching and joining the two poles of the electro-magnet in the above cut, is the *axis*, or line of *axial* action; at right angles to it is another line, called the *equator*, in which bodies

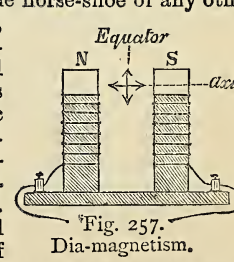


Fig. 257.
Dia-magnetism.

of a *dia-magnetic* character arrange themselves during the influence of magnetic action.

For example, if a piece of iron, steel, cobalt, or a magnetised needle, be placed between the poles N and S, they would, each and all, arrange themselves *axially ;* that is, one of their extremities would point to one pole, and one to the other, in the line marked *axis* in the preceding cut. But if a dia-magnetic body—such, for example, as the heavy glass already described, and an immense number of others—be acted upon by the magnetic lines of force, such dia-magnetics would arrange themselves at right angles to the magnetics; that is, they would take up a line or position represented by the line marked *equator* in the preceding cut; or, in other words, they would take an *equatorial* position.

It may, perhaps, assist the comprehension of the unscientific reader, if we still further illustrate this fact by reference to geography. A map or globe is marked by lines representing latitude and longitude. Now, supposing a powerful magnet to have its poles in the north and south of the earth, a natural or artificial magnet would arrange itself in a line corresponding with the meridian or longitude lines. But a dia-magnetic body, under the same influence, would not do so; it would take up a position corresponding to the equator of the map or globe. Therefore, simply, the position of a *magnetised body* between the poles of a magnet is identical with the line representing *longitude* on a map, whilst that of a *dia-magnetic* corresponds with the lines of *latitude.* It is of great importance that this distinctive difference be well understood, because on that will depend every chance of the reader understanding the nature, importance, &c., of Faraday's discoveries.

Series XX. of Faraday's *Researches* embraces the consideration of *New Magnetic Actions, and the Magnetic Condition of all Matter; Apparatus required; Action of Magnets on Heavy Glass; Action of Magnets or other substances acting Magnetically on Light; Action of Magnets on Metals generally.* As will be perceived, therefore, he passes from the subject of the magnetic action on light to consider it as affecting all matters; and thus he succeeded in experimentally and theoretically generalising the actions, relations, and affections of magnetism. He generously gives to Becquerel the credit of being amongst the first to point out "the magnetic actions excited in all bodies by the influence of very energetic magnets," which that philosopher first suggested in a paper read to the Academy of Sciences, Paris, in September, 1827, and published in the *Annales de Chimie*, vol. xxxvi., p. 337. Becquerel, however, had not in any way hit upon the idea or facts of dia-magnetism. Coulomb had discovered that a needle of wood, under certain conditions, would point in a direction at right angles, or across the magnetic curves; but neither he nor Becquerel arrived at any satisfactory explanation of the cause of the phenomenon.

For the present we may neglect to notice the apparatus that Faraday employed; because, except in certain comparatively minor particulars, its arrangement has already been described when we defined the terms axial and equatorial.

His first attempt at influencing a non-natural-magnetic body was exercised on the heavy glass, or silicated borate of lead, already described. It was suspended by a thread centrally between the poles of a powerful electro-magnet, and allowed to become at rest. "The magnet was then thrown into action by making contact with the voltaic battery. Immediately the bar of glass moved, turning round its point of suspension into a position *across* the magnetic curve or line of force; and after a few vibrations, took up its place of rest there. On being displaced by the hand from the position, it returned to it; and this occurred many times in succession."

It would be tedious to repeat the numerous experiments that Faraday tried for the purpose of showing that this action was the direct result of that of the magnetic force on the mass or particles of the heavy glass. He found two positions of equilibrium for the bar; one stable, and the other unstable. When in the direction of the axis, or magnetic line of force, the completion of the electric communication caused no change of place; but if it were in the least oblique to that position, then the obliquity increased until the bar arrived at an equatorial position. Or if the bar was originally in the equatorial position, then the magnetism caused no further changes, but retained it there.

He remarks, accordingly—"Here, then, we have a magnetic bar which points east and west [equatorially] in relation to north and south poles [or the axial direction]; *i.e.*, points perpendicularly to the lines of magnetic force." In other words, the bars of heavy glass took the position marked *equator* in the preceding cut; that is, at right angles to the line marked *axis* in the same engraving.

He also found, that although, under all circumstances, the bar of glass had a definite direction—that is, east and west—still it was not polar: in other words, either side pointed indifferently east and west; and, if the direction of the current was changed, no polar effect was induced. For example, if the direction of the current of electricity was changed, so that the north pole of the magnet was made a south one, and *vice versâ*, still the direction of the bar was unchanged. He accordingly remarks (§ 2,274)—"Here, therefore, we have magnetic repulsion without polarity; *i. e.*, without reference to a particular pole of the magnet, for either pole will repel the substance, and both poles will repel it at once. The heavy glass, although subject to magnetic action, cannot be considered as magnetic in the usual acceptation of the term, or as iron, nickel, cobalt, and their compounds. It presents to us, under these circumstances, a magnetic property new to our knowledge; and although the phenomena are very different, in their nature and character, to those presented by the action of heavy glass on light,

still they appear to be dependent on, or connected with, the same condition of the glass as made it then effective, and, therefore, with these phenomena, proves the reality of this new condition."

Having obtained these interesting results, showing the action of magnetism on a body that was certainly non-magnetic, in the common acceptation of the term, Faraday proceeded to trials of other bodies, in all states, and of all kinds and forms. He remarks—

"I then proceeded to subject a great number of bodies, taken from every class, to the magnetic forces ; and will, to illustrate the variety in the nature of the substances, give a comparatively short list of crystalline [crystallised it should be], amorphous, liquid, and organic bodies. When the bodies were fluid I enclosed them in thin glass tubes. Flint glass points equatorially ; but, if the tube be of very thin glass, this effect is found to be small when the tube is experimented with alone : afterwards, when it is filled with liquid, and examined, the effect is such that there is no fear of mistaking that due to the glass for that of the fluid. The tubes must not be closed with sealing-wax, or any ordinary substance taken at random, for [as will be afterwards seen] these are generally magnetic." The form of tube used by Faraday is figured below. These tubes had a very narrow aperture, as seen at *a*, by which they were filled, and which, being so small, prevented any risk of the fluid running out during the experiment.

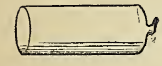


Fig. 258.

The substances, or dia-magnetics, to which Faraday referred as above, and which arranged themselves *equatorially*—that is, at right lines to the axis of the magnetic curves or force—were, amongst many others, as follows :—

Table of Equatorials, or Dia-magnetics.

Rock Crystal (pure Quartz).
Sulphate of Lime (Plaster of Paris).
Sulphate of Baryta (heavy Spar).
Sulphate of Soda (Glauber's Salts).
Sulphate of Magnesia (Epsom Salts).
Alum.
Muriate of Ammonia (Sal-ammoniac).
Chloride of Lead.
Chloride of Sodium (Common Salt).
Nitrate of Potass (Nitre).
Nitrate of Lead.
Carbonate of Soda.
Iceland Spar (Calcite).
Acetate (Sugar) of Lead.
Tartrate of Potass and Antimony.
Tartrate of Potass and Soda.
Tartaric Acid.
Citric Acid.
Water.
Alcohol (highly rectified Spirits of Wine).
Ether (Sulphuric).
Sulphuric Acid.
Muriatic (Hydrochloric) Acid.
Solutions of various Alkaline and Earth Salts.
Glass.
Litharge.
White Arsenic (Arsenious Acid).
Iodine.
Phosphorus.
Sulphur.
Resin.
Spermaceti.
Caffeine.
Cinchona.
Wax from Shell-lac.
Sealing-wax.
Olive Oil.
Oil of Turpentine.
Jet.
Caoutchouc (India-rubber).
Sugar.
Starch.
Gum Arabic.
Wood.
Ivory.
Mutton, dried.
Beef, fresh.
Beef, dried.
Blood, fresh.
Blood, dried.
Leather.
Apple.
Bread.

In looking over this heterogeneous list, we may well agree with Faraday when he says—

"It is curious to see such a list of bodies presenting on a sudden this remarkable property ; and it is strange to find a piece of wood or beef, or apple, obedient to, or repelled by, a magnet. If a man could be suspended with sufficient delicacy, after the manner of Dufay, and placed in the magnetic field, he would point equatorially ; for all the substances of which he is formed, including the blood, possess this property."

Faraday found that phosphorus especially, and, in a less degree, sulphur and india-rubber, were about the most powerful equatorials, or dia-magnetics. He found no difference in any of the crystalline bodies, in respect to single and double refracting power. But he noticed that the setting equatorially "depends upon the form of the body ; and the diversity of forms presented by the different substances in the preceding list was very great : still the general result, that elongation in one direction was sufficient to make them take up an equatorial position, was well established. It did not seem to matter whether the bodies were in the form of a solid mass or in powder ; for a block of Iceland spar, and the same in powder, possessed an equal directive or equatorial power."

He remarks, that he was much impressed with the fact "that blood was not magnetic, nor any of the specimens tried of red muscular fibre of beef and mutton." All these contain oxide of iron, which, indeed, is the cause of the colouring matter of the blood. He continues—"This

was the more striking, because iron is *always*, and in almost all *states*, magnetic. But, in respect to this point, it may be observed, that the ordinary magnetic property of matter and this new [dia-magnetic] property are, in their effects, opposed to each other; and that when this property [the dia-magnetic] is strong, it may overcome a very slight degree of the ordinary magnetic force, just as also a certain amount of ordinary magnetic force may oppose and effectually hide the presence of this [the dia-magnetic] force. It is this circumstance which makes it so necessary to be careful in examining the magnetic condition of the bodies in the first instance."

Faraday found the following substances to be slightly magnetic; that is, pointing axially between the poles of a magnet, just as a piece of iron would do.

Some Magnetic or Axially-pointing Bodies.

Paper.
Sealing-wax.
China (Indian) Ink.
Berlin Porcelain Ware.
Silkworm Gut.
Asbestos.
Fluor (Derbyshire) Spar.
Red Lead.
Vermilion.
Peroxide of Lead.
Sulphate of Zinc.
Tourmaline.
Plumbago (Black-lead).
Shell-lac.
Charcoal.

In some of these cases the magnetism was generally diffused through the body; but in others it was limited to a particular part. From this fact, although Faraday does not suggest it, we might suppose that particles of iron were present. This is commonly the case in paper, owing to abrasion of portions of the machinery by which it is made.

It is impossible not to perceive that, in these researches, Faraday made one of the most important and astonishing additions to our knowledge of physical science that had been effected—a knowledge, in fact, utterly subversive of our previous information, and revealing facts and laws that could scarcely have been conceived. Indeed, as we already have remarked, he generalised the phenomena of magnetism to an extent that really places it, in respect to universality, in the rank of gravitation and cohesion. Animal magnetism, in a philosophical sense, he proved to exist; for, as he observes, if a man could be delicately poised between the poles of a very powerful magnet, he would point equatorially, or across the lines of magnetic force. Perhaps from this may be concluded that there is great reason and truth in the idea that, in sleep, it is desirable to take a direction nearly that of the magnetic meridian; that is, nearly north and south. Years ago we ridiculed the idea; but, from careful observation, have arrived at the conclusion that a much better and refreshing rest can be obtained in such a position, than in one wherein the body is placed equatorially, or east and west. It is quite certain that if the body of a man could be acted on by the poles of a powerful magnet, terrestrial magnetism, which so infinitely transcends all the magnets that science and art can produce, should have a correspondingly increased effect. Far be it from us to countenance the impostures of mesmerism, electro-biology, animal magnetism, *et hoc omne genus.* We merely offer these observations as based on the facts proved by Faraday, and that may be philosophically induced from such facts.

The *Action of Magnets on Metals generally* is the next subject dealt with in Series XX.; and in this Faraday enters into a lengthened investigation of magnetic bodies of a metallic character. In this department of scientific research he largely advanced our knowledge of the laws of magnetism.

Under the head of MAGNETISM, we have already detailed some of the most interesting laws that have been discovered from the earliest to the present day, and given an account of the labours of many eminent men who have advanced that branch of experimental philosophy to its present position. But, as there stated, until the discovery of electro-magnetism and dia-magnetism, all our ideas of the laws, cause, and theories of magnetism, were more or less tinged with error. In the article referred to, will be found accounts of various theories that were offered by Coulomb, and others, to account for the cause of terrestrial and general magnetism—most, if not all of them, being exceedingly ingenious; but all lacking the essential element of truth.

When, however, it was found that dynamic, or current electricity, was capable of inducing magnetism; that an electrified wire would rotate round a magnet, and the latter round an electrified wire, as shown first by Faraday; that, again, magnetism could induce an electric current of both quantity and intensity; and, lastly, in this series of Faraday's great discoveries, that bodies or matter of every kind, and even light, are subject to magnetic action—our views of magnetic phenomena became, with the facts accumulated, so extended, that it was possible to frame a theory of the cause of magnetism that approached the truth infinitely nearer than could be effected when Faraday, in 1820, commenced his researches. But even twenty-five years afterwards, the dawn of true knowledge of the subject was but just beginning to be seen.

In the introduction to MAGNETISM, we have shown that the general phenomena of magnetism were known to the ancients. In Europe, such knowledge was confined, at early periods, to an acquaintance with the attractive power; but in China the polarity of the magnet was early known. For a period of about twenty centuries, however, the science was at a standstill; and it was only at the beginning of the present century that an active study of magnetism was commenced.

In opening the subject of the action of mag-

nets on metals generally, Faraday remarks (Series XX., § 2,287, *et seq.*):—

"The metals, as a class, stand amongst bodies having a high and distinct interest in relation both to magnetic and electric forces; and might, at first, well be expected to present some peculiar phenomena in relation to the striking property found to be possessed in common by so large a number of substances, so varied in their general characters. As yet, no distinction associated with conduction or non-conduction, transparent or opaque, solid or liquid, crystalline or amorphous, whole or broken, has presented itself. Whether the metals, distinct as they are as a class, would fall into the great generalisation, or whether, at last, a separation would occur, was to me a point of the highest interest.

"That the metals iron, nickel, and cobalt, would stand in a distinct class, appeared almost undoubted; and it will be for the advantage of the inquiry that I should consider them in a section apart by themselves. Further, if any other metals appeared to be magnetic, as these are, it would be right and expedient to include them in the same class."

Faraday's test of magnetism, in these researches, was as follows:—"If a bar of the metal to be examined, about two inches long, was suspended in the magnetic field, and being at first oblique to the axial lines, was, upon the supervention of the magnetic forces, drawn into the axial position [see *ante*, p. 447, Fig. 257], instead of being driven into the equatorial line, or remaining in some oblique direction, then I concluded that it was magnetic. Or if, being near one magnetic pole, it was attracted by the pole, instead of being repelled, then I concluded that it was magnetic. It is evident that the test is not strict, because a body may have a slight degree of magnetic force, and yet the power of the new property (dia-magnetism) be so great as to neutralise or surpass it. In the first case it might seem neither to have the one property nor the other; in the second case, it might appear free from magnetism, and possessing the special property in a slight degree."

In his results, by the method above described, Faraday came to the conclusion that the following metals showed no trace of magnetism: viz.—

Antimony.	Lead.
Bismuth.	Mercury.
Cadmium.	Silver.
Copper.	Tin.
Gold.	Zinc.

But he includes with iron, nickel, and cobalt, the following, as magnetic: viz.—

Platinum.
Palladium.
Titanium.

He states that "all the non-magnetic metals are subject to the magnetic power, and produce the same general effects as the large class of bodies already described. [See list of dia-magnetics, given at p. 449, *ante*.] The force which they manifest they possess in different degrees. Antimony and bismuth show it well, and bismuth appears to be especially fitted for the purpose. It excels heavy glass, or borate of lead, and, perhaps, phosphorus; and a small bar or cylinder of it, about two inches long, and from 0·25 to 0·5 of an inch in width, is as well fitted to show the various peculiar phenomena [of dia-magnetism] as anything I have yet submitted to examination." He adds that there are many peculiarities in the action of bismuth; but it points well, and is well repelled when immersed in water, alcohol, ether, oil, mercury, &c.; and also when enclosed in vessels of earth, glass, copper, lead, &c.; or when plates of from three-quarters to an inch in thickness, of bismuth, copper, or lead intervene. Even when a bismuth cube was put into an iron vessel, $2\frac{1}{2}$ inches in diameter, and 0·17 inch thick, it was well and freely repelled by the magnetic pole. If the bismuth were in a solid mass, or as powder, no difference of effect or intensity was observable.

Faraday discovered that copper, and several of the metals, presented peculiar phenomena when subjected to the action of magnetic force, which tended to mark the dia-magnetic effects. They arise from changes in the amount, &c., of motion when the body is under magnetic influence. He accounted for these anomalous results on the ground of the excellent conducting powers of copper for electric currents, the gradual acquisition and loss of magnetic power in the iron core, if the electro-magnet be employed, and to the production of induced currents of magneto-electricity. A peculiar sluggishness of motion was observed in all the dia-magnetic metals; but most especially so in respect to copper. Relative to this subject are the facts that it is all but impossible to rotate a copper disc between the poles of an electro-magnet; and, again, that rotating discs of copper and other metals act on a magnetic needle. (See article on MAGNETISM.)

In Series XXI. of *Researches*, Faraday enters on two important subjects—namely, the action of magnets on the magnetic metals and their compounds, and the action of magnets on air and various gases. He first points out that, as is well known, alterations in temperature greatly affect the magnetic properties of iron, &c. "At certain temperatures they lose their usual property, and become, to ordinary test and observation, non-magnetic; then entering into the list of dia-magnetic bodies, and acting in like manner with them. Closer investigation, however, has shown me that they are still very different to other bodies, and that though inactive when hot, on common magnets or to common tests, they are not so absolutely, but retain a certain amount of magnetic power whatever their temperature; and also that this power is the same in character with that which they ordinarily possess."

He then details experiments with iron and nickel at varying temperatures; and proved, however much the signs of magnetism were destroyed by heat to ordinary tests, yet they were shown when the metals were submitted to the electro-magnet.

His investigations into the nature of the oxides and salts of the magnetic metals, resulted in showing that the former partake of the magnetic characters of the latter. He found all the salts of iron magnetic. Clean crystals of the proto-sulphate of iron were attracted, and pointed axially well; so also did the dry salt. He found the proto-chloride, per-chloride, iodide, proto-sulphate, per-sulphate, proto-phosphate, per-phosphate, nitrate, carbonate of iron, Prussian blue (ferro-cyanide of iron), bog iron ore, hematite, chromate of iron (native), yellow sulphide, arsenical pyrites, copper pyrites (containing iron), and many other native ferruginous compounds, all magnetic. Green bottle glass was highly magnetic from the iron it contained, and crown-glass less so, from the same cause. He also found that solutions of the salts of magnetic metals were also magnetic; and thus showed, that although, by all ordinary tests, such phenomena would not appear, the method that he adopted was sufficient for that purpose. The results with nickel and cobalt were the same as with iron in all cases; and heat applied to any of the magnetic solutions had no effect in diminishing the character of them by suspending tubes containing metallic solutions in vessels containing the same: he discovered, that when the tube contained a stronger solution than that which surrounded it, it was attracted to the pole of the electro-magnet; but when its solution was the weaker of the two, it was repelled. The latter phenomena were, as to appearance, in every respect the same as those presented in the repulsion of heavy glass, bismuth, or any other dia-magnetic body in air.

Faraday next details his experiments with various other metals. Titanium, manganese, cerium, chromium, were magnetic. Impure lead feebly so; whilst pure lead was dia-magnetic. Platinum and palladium were feebly magnetic. Arsenic and silver were decidedly non-magnetic; and so were antimony, bismuth, the alkaline, and the alkaline earth metals.

He attempted to arrange the metals in what he conceived to be a scale, commencing with the highest magnetic, and closing with the lowest. Iron belonged to the head of the first class, and bismuth to that of the dia-magnetics. The following is the list so produced, arranged differently from that given by Faraday, but in the order of sequence downwards, from the highest magnetic at the top of the list, to the highest dia-magnetic at the bottom. Between the two he conceived a zero, or 0°, which he supposed to be the condition of a substance indifferent to the magnetic force, as respects attraction or repulsion in air or space. Consequently, in the following list the force of the magnetics increases upwards from zero-mark, whilst that of the dia-magnetics increases downwards from that point :—

Iron.	Magnetics.
Nickel.	
Cobalt.	
Manganese.	
Chromium.	
Cerium.	
Titanium.	
Palladium.	
Platinum.	
Osmium.	
0°, or zero.	
Tungsten.	Dia-magnetics.
Iridium.	
Rhodium.	
Uranium.	
Arsenic.	
Gold.	
Copper.	
Silver.	
Lead.	
Mercury.	
Sodium.	
Cadmium.	
Tin.	
Zinc.	
Antimony.	
Bismuth.	

He next relates a most interesting series of experiments resulting from his investigations of the—

Action of Magnets on Air and Gases.—He observes—"It was impossible to advance, in an experimental investigation of the kind now described, without having the mind impressed with various theoretical views of the mode of action of the bodies producing the phenomena. In the passing consideration of these views, the apparently middle condition which *air* held between magnetic and dia-magnetic substances was of the utmost interest, and led to many experiments upon its probable influence." In a subsequent portion of this work we shall fully describe the interesting discoveries that Faraday made on the magnetic relations of flame and gases.

He recounts numerous experiments on air, vapours, and gases; and comes to the conclusion—"In every kind of trial, and in every form of experiment, the gases and vapours still occupy a medium position between the magnetic and the dia-magnetic classes. Further, whatever the chemical or other properties of the substances; however different the specific gravity, or however varied in their own degree or rarefaction, they all become alike in their magnetic relation, and, apparently, equivalent to a perfect vacuum. Bodies which are very marked as dia-magnetic substances [when solid or liquid], lose all traces of this character when they become vaporous."

The latter Faraday proved by suspending a tube of liquid sulphurous acid in gaseous sulphurous acid, when, under the magnetic influence, the liquid pointed well equatorially. He surrounded liquid nitrous acid with gaseous nitrous acid : the liquid pointed well equatorially; and so on with other liquids capable of becoming converted into vapours.

He gives a table of general substances, magnetic and non-magnetic, as follows; iron being the greatest magnetic, and bismuth the greatest dia-magnetic, with a neutral point between them of 0° of air, and a vacuum as follows :—

Iron, magnetic.
Nickel.
Cobalt.
Manganese.
Palladium.
Crown-glass.
Platinum.
Osmium.
0^0 air and vacuum, neutral.
Arsenic, dia-magnetic.
Ether.
Alcohol.
Gold.
Water.
Mercury.
Flint-glass.
Tin.
Heavy glass.
Antimony.
Phosphorus.
Bismuth.

He remarks—"It is very interesting to observe that metals are the substances which stand at the extremity of the list, being, of all bodies, those which are most powerfully opposed to each in their magnetic condition. It is also a very remarkable circumstance, that these differences and departures from the medium condition are, in the metals, at the two extremes [of the list], iron and bismuth, associated with a small conducting power for [current] electricity. At the same time, the contrast between these metals, as to their fibrous and granular state, their malleable and brittle character, will press upon the mind whilst contemplating the possible condition of the molecules when subjected to magnetic force."

On the general result of these facts, he observes—"All matter appears to be subject to the magnetic force, as universally as it is to the gravitating, the electric, and the chemical, or cohesive forces; for that which is not affected by it in the manner of ordinary magnetic action, is affected in the manner that has been described; the matter possessing, for the time, the solid or fluid state. Hence substances appear to arrange themselves into two great divisions—the *magnetic*, and that which I have called the *dia-magnetic* classes; and between these classes the contrast is so great and direct, though varying in degree, that where a substance from the one class be attracted, a body from the other will be repelled; and where a bar of the one will assume a certain position, a bar of the other will acquire a position at right angles to it."

He considers the cause of all these results to be due "to an action upon the molecules, or the mass of the substances acted upon, by which they are thrown into different conditions, and affected accordingly."

In his explanations of the action of force on matter, Faraday maintains the old doctrine first propounded by Sir Isaac Newton—that matter is composed of infinitely hard and physically indivisible bodies, called *atoms*, from the Greek, which signifies *indivisible*. Faraday's speculations concerning the nature of matter have already been noticed in connection with the subjects of Induction, Conduction, and Insulation, in regard to static electricity. There he speaks of the action of contiguous particles, just as, in his dia-magnetic hypothesis, he refers all the results to disturbance, or fresh arrangements of the molecules or particles of a body.

Many years after his researches in dia-magnetism were completed, and, indeed, after Faraday had become incapable of any scientific pursuit, other opinions gained ground in respect to the ultimate nature of matter. The old definitions gradually became discredited, and a much more refined idea became prevalent, founded on what are called vortex atoms. The old and new views of the nature of matter were ably discussed in a paper read before the Edinburgh Royal Society, in November, 1867, about three months after Faraday had been laid in his tomb. We shall avail ourselves of an abstract of that paper, so that our readers may, by its perusal, study the further description of Faraday's researches, especially in respect to crystalline bodies, and the magnetic affection of matter in general, under the new light that has been given of the properties of gaseous, liquid, and solid matter.

The author of the paper was Sir William Thomson, whose name has so repeatedly been before the scientific world as a natural philosopher of great eminence, but who is more popularly known in connection with the successful laying and working of the Atlantic cable in 1866. An abstract of his views is as follows:—

After noticing Helmholtz's admirable discovery of the law of vortex motion in a perfect liquid—that is, in a probable fluid perfectly destitute of viscosity (or fluid friction)—Sir William said that "this discovery inevitably suggests the idea that Helmholtz's rings are the only true atoms. For the only pretext seeming to justify the monstrous assumption of infinitely strong and infinitely rigid pieces of matter, the existence of which is asserted as a probable hypothesis by some of the greatest modern chemists in their rashly-worded introductory statement, is that urged by Lucretius, and adopted by Newton—that it seems necessary to account for the unalterable distinguishing qualities of different kinds of matter. But Helmholtz has proved an absolute unalterable quality in the motion of any portion of a perfect liquid, in which the peculiar motion which he calls 'wirbel-bewegung' has been once created. Thus, any portion of a perfect liquid which has 'wirbel-bewegung' has one recommendation of Lucretius' atoms—infinitely perennial specific quality. To generate or to destroy 'wirbel-bewegung' in a perfect fluid can only be an act of creative power. Lucretius' atoms does not explain any of the properties of matter without attributing them to the atom itself. Thus the 'clash of atoms,' as it has been well called, has been invoked by his modern followers to account for the elasticity of gases. Every other property of matter has similarly required an assumption of specific forces pertaining to the atom. It is as easy (and as improbable, if not more so) to assume

whatever specific forces may be required in any portion of matter which possesses the 'wirbel-bewegung,' as in a solid indivisible piece of matter; and hence the Lucretius atom has no *prima facie* advantage over the Helmholtz atom." A magnificent display of smoke-rings, which he recently had the pleasure of witnessing in Professor Tait's lecture-room, diminished by one the number of assumptions required to explain the properties of matter, on the hypothesis that all bodies are composed of vortex atoms in a perfect homogeneous liquid. Two smoke-rings were frequently seen to bound obliquely from one another, shaking violently from the effects of the shock. The effect was very similar to that observable in two large india-rubber rings striking one another in the air. The elasticity of each smoke-ring seemed no further from perfection than might be expected in a solid india-rubber ring of the same shape, from what we know of the viscosity of india-rubber. Of course, this kinetic elasticity of form is perfect elasticity for vortex rings in a perfect liquid. This is at least as good a beginning as the "clash of atoms" to account for the elasticity of gases. It seems most probable that the beautiful investigations of D. Bernouilli, Herapath, Joule, Krönig, Clausius, and Maxwell, on the various thermo-dynamic properties of gases, may have all the positive assumptions they have been obliged to make as to mutual forces between two atoms, and kinetic energy acquired by individual atoms or molecules satisfied by vortex rings, without requiring any other property in the matter whose motion composes them than inertia and incompressible occupation of space. A full mathematical investigation of the mutual action between two vortex rings of any given magnitudes and velocities, passing one another in any two lines, so directed that they never come nearer one another than a large multiple of the diameter of either, is a perfectly solvable mathematical problem; and the novelty of the circumstances contemplated presents difficulties of an exciting character. Its solution will become the foundation of a proposed new kinetic theory of gases. Another very interesting problem is presented by the mutual action between closely-packed vortex atoms. For the case of cubically-packed vortices he had succeeded in finding the solution expressing the motion of every particle of the fluid. By considering the variation of kinetic energy due to any variation in the sides of one of the rectangular boundaries, its area remaining constant, he found the corresponding modulus of rigidity thus constituted. It was quite certain that closely-packed vortex atoms, even of different dimensions and configurations, must produce in the aggregate an elasticity agreeing with the elasticity of real solids. Diagrams were shown to illustrate the knotted or knitted vortex atoms, the endless variety of which is infinitely more than sufficient to explain the varieties and allotropies of known simple bodies and their mutual affinities. It is to be remarked that two ring atoms linked together, or one knotted in any manner with its ends meeting, constitute a system which, however it may be altered in shape, can never deviate from its own peculiarity of multiple continuity, it being impossible for the matter in any line of vortex motion to go through the line of any other matter in such motion, or any other part of its own line. In fact, a closed line of vortex matter is literally indivisible.

Of course, the *vortex atom* theory is just as tenable, so far as founded on experiment, as the Newtonian theory; in other words, they can neither be proved or disproved; and, probably, to the end of time the problem will remain unsolved.

It is natural in man to attempt to solve problems that have hitherto been considered as incapable of solution; and there is an unfortunate tendency in our age to assume as possibly or really true, that which has to be proved. Often, again, the wildest theories are, and must be, based on insufficient data. For the present, we have no hesitation in classing the *vortex atom* one in that category.

Returning now to the investigations of Faraday, he especially dwells on the comparison of the dia-magnetic action in nature of solids and liquids, and the analogous magnetisation of a ray of light, already fully described.

In reference to the amount of power, either in the production of direction, attraction, or repulsion, Faraday pointed out that, although apparently trifling, it is really very great. It is well known that, in respect to gravitative attraction, the force that can be exercised by a great mountain on a plummet held near it, is exceedingly trifling, and requires the most careful observation to be noticed; and, similarly, in the experiments that were undertaken to weigh the earth, the attraction of a large mass of metal on a small one was also but trifling. But in the dia-magnetic experiments of Faraday, comparatively slight causes produced remarkable and decisive effects. Precisely the same may be remarked on the powers of attraction, &c., between two magnetised bodies, or between a magnetised and an unmagnetised one. Hence arose the early opinion that magnetism was a force of a very special nature—an idea that was more or less maintained until Faraday, by his masterly researches, proved that magnetism, in one or other form, is an affection or quality of all matter; and that this can be divided into two great classes, respectively called magnetics and dia-magnetics.

In respect to this question, Faraday remarks as follows :—

"The amount of this power in dia-magnetic substances seems to be very small when estimated by its dynamic effect; but the motion which it can generate is, perhaps, not the most striking measure of the force; and it is probable that, when its nature is more intimately known to us, other effects produced by it, and other indications and measures of its powers, will come to our knowledge; and, perhaps, even new classes of phenomena will serve to make it manifest, and indicate its operation. It is very striking to observe the feeble condition of a helix when alone, and the astonishing

force which, in giving and receiving, it manifests by association with a piece of soft iron. So, also, we may hope for some analogous development of this element of power, so new as yet to our experience. It cannot for a moment be supposed, that being given to natural bodies, it is either superfluous, insufficient, or unnecessary. It doubtless has its appointed office, and that one which relates to the whole mass of the globe; and it is, probably, because of its relation to the whole earth that its amount is necessarily so small (so to speak) in the portions of matter which we handle and subject to experiment. And, small as it is, how vastly greater is this force, even in dynamic results, than the mighty power of gravitation, for instance, which binds the whole universe together when manifested by masses of matter of equal magnitude." In a following section he observes—

"When we consider the magnetic condition of the earth as a whole, without reference to its possible relation to the sun, and reflect upon the enormous amount of dia-magnetic matters which, to our knowledge, forms its crust; and when we remember that magnetic curves of a certain amount of force, and universal in their presence, are passing through these matters, and keeping them constantly in that state of tension, and therefore of action, we cannot doubt but that some great purpose of utility to the system, and us, its inhabitants, is thereby fulfilled, which soon we shall have the pleasure of searching out.

"Of the substances which compose the crust of the earth, by far the greater portion belongs to the dia-magnetic class: and though ferruginous and other magnetic matters, being more energetic in their action, are, consequently, more striking in their phenomena, we should be hasty in assuming that, therefore, they overrule entirely the effect of the former [dia-magnetic] bodies. As regards the ocean, lakes, rivers, and the atmosphere, they will exert their peculiar effect almost uninfluenced by any magnetic matter in them. By adjusting water and a salt of iron together, I obtained a solution inactive in air; that is, by a due association of the forces of a body from each class—water and a salt of iron—the magnetic force of the latter was entirely counteracted by the dia-magnetic force of the former, and the mixture was neither attracted nor repelled. To produce this effect, it requires that more than 48·6 grains of crystallised proto-sulphate of iron should be added to ten cubic inches of water (for these proportions gave a solution which still set equatorially)—a quantity so large that I was greatly astonished on observing the power of the water to overcome it. It is, therefore, not at all unlikely that many of the masses that form the crust of this our globe, may have an excess of dia-magnetic power, and act accordingly.

"Though the general disposition of the magnetic curves, which penetrate and surround our globe, resemble those of a very short magnet, and, therefore, give lines of force rapidly diverging in their general form, yet the magnitude of the system prevents us from observing any diminution of their power within small limits; so that, probably, any attempt, on the surface of the earth, to observe the tendency of matter to pass from stronger to weaker places of action would fail. Theoretically, however, and at first sight, I think a pound of bismuth, or of water, estimated at the equator [magnetic], when the magnetic needle does not dip, ought to weigh less when taken into latitudes where the dip is considerable; whilst a pound of iron, nickel, or cobalt, ought to weigh more.* If such should really prove to be the case, then a ball of iron, and another of bismuth, attached to the ends of a delicate balance beam, should cause that beam to take different inclinations on different parts of the surface of the earth; and it does not seem quite impossible, that an instrument to measure one of the conditions of terrestrial magnetic force, might be constructed on such a principle.

"If one might speculate upon the effect of the whole system of curves upon very large masses, and these masses were in plates and rings, then they would, according to analogy with the magnetic field, place themselves equatorially. If Saturn were a magnet, like as the earth is, and his ring composed of dia-magnetic substances, the tendency of the magnetic forces would be to place it in the position which it actually has.

"It is a curious sight to see a piece of wood, or of beef, or an apple, or a bottle of water, repelled by a magnet; or taking the leaf of a tree, and hanging it up between the poles, to observe it take an equatorial position. Whether any similar effects occur in nature, among the myriads of forms which, upon all parts of its surface, are surrounded with air, and are subject to the action of lines of magnetic force, is a question which can only be answered by future observation.

"Of the interior of the earth we know nothing; but there are many reasons for believing that it is of a high temperature. On this supposition I have remarked, that, at a certain distance from the surface, downwards, magnetic substances must be entirely destitute, either of the power of retaining magnetism, or becoming magnetic by induction from currents in the crust, or otherwise. This is evidently an error. That the iron, &c., can retain no magnetic condition of itself, is, very probably, true; but that the magnetic metals, and all their compounds, retain a certain power of becoming magnetic by induction, whatever their temperature, has now been proved [by Faraday showing that, at a red-hot temperature, a powerful electro-magnet affected iron, although an ordinary magnet failed to do so]. The deep magnetic contents of the earth, therefore, though they probably do not constitute of themselves a central magnet, are just in the condition to act as a very weak iron core to the currents around them, or other inducing actions, and, very likely, are highly important in this respect."

He also speculates on the probability, that if

* This supposition of Faraday becomes a fact in connection with gravitation, a body weighing heavier at the poles than at the equator.

the magnetism of the earth has anything to do with the sun, the magnetic effect will, in some measure, be due to the action of solar light. "In that expectation the air seems most strikingly placed round our sphere, investing it with a transparent dia-magnetic, which, therefore, is permeable to his rays, and, at the same time, moving with great velocity across them." But Faraday merely threw out a hint as to the possibility of such a case, without in the least committing himself to the expression of an opinion of its truth, simply because no experimental investigation had been made in the matter. In this, as in all other speculative questions, he preferred to adhere to rigid experiment before attempting to form a theory.

In reviewing the account we have given of Faraday's dia-magnetic discoveries, it is impossible almost to find a parallel with the patient step-by-step process by which he at last arrived at results that cannot at present be estimated at their just value. His successors still rely on his experiments and results as a basis for further investigations of dia-magnetic phenomena. The subject of itself is sufficiently abstruse to confine its study to those who simply pursue science for its own sake. At present we have had no special practical applications of Faraday's dia-magnetic discoveries. To a large extent spectrum analysis has aided us in the investigation of the general chemical character of bodies of all kinds, whether elementary or compound. So far as we can see at present, the results of the discoveries of Faraday in the line of dia-magnetism must be entirely confined to the development of our knowledge of physical, or, perhaps, more correctly, cosmical laws that have hitherto escaped our research. But the absence of present practical result by no means invalidates the value of what, for the moment, we are compelled to regard, to a large extent, in the abstract. Some of the most eminent discoveries in science have been of a similar kind. The discovery of the composition and decomposition of water by Sir Anthony Carlisle, and of the decomposition of the alkalies by Sir Humphry Davy, promised no results. Similarly it might be said of the deflection of the magnetic needle by Œrsted; but these two laid the foundation of two of the most important applications of science—electro-metallurgy and the electric telegraph. Similarly, we may predicate of Faraday's discoveries of the magnetic and dia-magnetic affections of bodies, that while at present our knowledge of natural phenomena prevents our seeing their practical value in the future, they may at some distant period reveal a new light in philosophy that may eclipse some of the most brilliant efforts of human intellect that have preceded them.

Numerous arrangements have been proposed to enable the student to follow in the steps of Faraday in the experimental investigation of dia-magnetic phenomena. Plücker suggested an ingenious arrangement, and to him we are indebted for greatly extending our knowledge of dia-magnetism.

Having thus detailed some of the most important results that Faraday obtained in his investigations of the dia-magnetic and magnetic properties of matter generally, we shall describe some of the apparatus that may be employed for such experiments.

A useful form of apparatus for dia-magnetic investigation is represented in the following cut:—*a a'* are two poles of an electro-magnet, on each of which is a bar of soft iron, brought

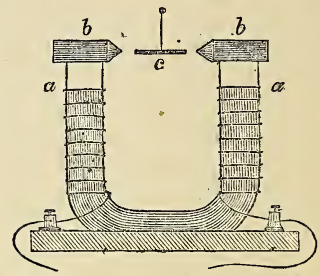


Fig. 259.—Wylde's Polariscope.

into a cone form, so that the apex of each cone shall point to the body, *c*, to be experimented on; *b b*, of course, become magnetic by the inductive action of the electro-magnetic poles.

An ingenious arrangement was suggested by Dr. Tyndall, of the Royal Institution, which was termed a *Polymagnet*: by means of it many of the most interesting of the phenomena of magnetism and electro-magnetism can be investigated. Its elaborate construction, however, renders it a costly piece of apparatus.

In experimenting on bismuth as a dia-magnetic, Faraday found many anomalies that, eventually, led him to the discovery of what he termed *Magnecrystallic force*. He remarks, Series XXII., § 2,454—"Many results, obtained by subjecting bismuth to the action of the magnet at various times, embarrassed me, and I have either been contented with an imperfect explanation, or have left them for future examination;" which he describes in the series of researches just named.

He prepared long cylinders of bismuth by melting that metal in glass tubes; and exposing some of these successively at random, by suspending them horizontally to the poles of the electro-magnet, he found that one pointed axially; the second, equatorially; the third, equatorially in one position, and obliquely equatorial if turned round on its axis 50° or 60°; the fourth, equatorially and axially under the same treatment; and all of them, if suspended perpendicularly, pointed well, vibrating about a final fixed position, which seemed to have no reference to the form of the cylinders. In all these cases the bismuth was strongly dia-magnetic, being repelled by a single magnetic pole, or passing off on either side from this axial line between the two poles. A similar piece of finely-grained or granular bismuth was, under the same circumstances, and at the same time, affected in a perfectly regular manner, taking up the equatorial position as a body simply dia-magnetic ought to do. The cause of these variations was finally traced to the regularly crystalline condition of the metallic cylinders.

Faraday proceeds to describe his further progress in respect to his inquiry into the crystalline polarity of bismuth as follows :—

"Some bismuth was crystallised in the usual manner by melting it in a clean iron ladle, allowing it partly to congeal, and then pouring away the internal fluid portion; pieces so obtained were then broken up by copper hammers and tools, and groups of the crystals separated, each group or piece consisting only of those crystals which were symmetrically arranged, and therefore likely to act in one direction. If any part of the fragments had been in contact with the iron ladle, it was cleared away by rubbing on sandstone and sand-paper. Pieces weighing from 18 grains to 100 grains were thus easily obtained.

"The electro-magnet employed in the first instance had movable terminations, which supplied either conical, round, or flat-faced poles. That the suspension of the bismnth might be readily effected, and unobjectionable as to magnetic influence, the following arrangement was generally adopted:—A single fibre of cocoon silk, from twelve to twenty-four inches in length, was attached to a fit support above, and made fast below to a piece of fine, straight, well-cleaned copper wire, about two inches in length; the lower end of the wire was twisted up into a little head, and then furnished with a pellet of cement, made by melting together a portion of pure white wax with about one-fourth of its weight of Canada balsam. The cement was soft enough to adhere, by pressure, to any dry substance, and sufficiently hard to sustain weights up to 300 grains, or even more. When prepared, the suspender was subjected by itself to the action of the magnet, to ascertain that it was free from any tendency to point or be [otherwise] affected; without which precaution no confidence could be reposed in the results of the experiments.

"A selected piece of bismuth, weighing twenty-five grains, was hung up between the poles of the magnet, and moved with great freedom. The constituent cubes were associated in the usual manner, being attached to each other chiefly in the line joining two opposite angles; and this line was in the greatest length of the piece. The instant that the magnetic force was [put] on, the bismuth vibrated strongly about a given line, in which at last it settled; and if moved out of that position, it returned, when at liberty, into it, pointing strongly, and having its greatest length *axial*.

"Another piece was then selected, having a flatter form, which, when subjected to the magnetic power, pointed with the same facility and force, but its greatest length was equatorial; still the line according to which the cubes tended to associate diametrally was, as before, in the *axial* direction. Other pieces were then taken, of different forms, or shaped into various forms by rubbing them down on stone; but they all pointed well, and took up a final position, which had no reference to the shape, but was manifestly dependent on the crystalline [crystal] condition of the substance."

Perhaps here we should inform our readers of the distinction that is held in science between the terms *crystalline* and *crystal*. The diamond, Iceland spar, aragonite, gold, iron, bismuth, and, perhaps, thousands of other objects form *crystals*; whilst, on the other hand, marble and sugar are *crystalline*: hence we have frequently done, and shall yet pursue when necessary, the same course—that of following his term *crystalline* with that of crystal, in brackets. Continuing his remarks :—

"In all these cases the bismuth was dia-magnetic, and strongly repelled by either magnetic pole or from the axial line. It was only affected whilst the magnetic force was present [or acting]. If set in a given constant position, perfectly determinate; and, if moved, always returned to it, unless the extent of motion was above 90°, and then the piece moved further round and took up a new position, diametrically opposed to the former, which it then retained with equal force, and in the same manner. This phenomenon is general in all the results I have to refer to; and I will express it by the word *diametral*—*diametral*, set or position.

"The effect occurs with a single magnetic pole; and it is then striking to observe a long piece of a substance so dia-magnetic as bismuth repelled, and yet at the same moment set round with force, axially or end on, as a piece of magnetic substance would do.

"Whether the magnetic poles are pointed, round, or flat-faced, still the effect on the bismuth is the same; nevertheless, the form of the poles has an important influence of a subordinate kind, and sometimes are much more fitted for these investigations than others."

Faraday varied his experiments in many ways, and found a variety of circumstances affected the results he obtained. He considered that magnecrystallic results "are altogether very different from those produced by diamagnetic action. They are equally distinct from those discovered and described by Plücker in his beautiful researches in relation to the optic axis [see *ante*, p. 435] to magnetic action; for there the force is equatorial, whereas here it is axial. So they appear to present to us a new force, or a new form of force, in the molecules of matter; which, for convenience sake, I will conventionally designate by a new word, as the *Magnecrystallic* force." Without going through all his experiments on the crystalline polarity of bismuth, we may add, that he defines (§ 2,479) the magnecrystallic force as not manifested by attraction or repulsion; "or, at least, it does not cause approach or recession, but gives *position* only. The law of action appears to be, that the *line or axis* of MAGNECRYSTALLIC *force* (being the resultant of the action of all the molecules) *tends to place itself parallel, or as a tangent, to the magnetic curve or line of magnetic force, passing through the place where the crystal is situated.*"

He did not find that crystals of bismuth acquire any power, either temporary or permanent, which they can bring *away* from the magnetic field. But he noticed, that on putting

the matter to experiment, a crystal of bismuth placed in a helix, or ring of wire carrying an electric current, pointed with its magnecrystallic axis parallel to the axis of the helix. This would, of course, result, provided the definition of the force, as given by Faraday, was correct.

Numerous other interesting particulars in reference to bismuth, antimony, and many other metals, in regard to the anomalies here under consideration, were arrived at by Faraday. He experimented with antimony, arsenic, and many other bodies, in respect to their crystalline polarity, and its relation to electric and magnetic forces; and the laws of what he termed the magnecrystallic force were noticed as affecting them all in a greater or less degree, but still so far as to appear as an affection of crystallised bodies, although he discovered certain exceptions.

Faraday was followed in these researches by other eminent men, the results of whose discoveries we shall briefly notice. From what has been stated, Faraday expresses the belief that the magnecrystallic force results from an induction exercised on the particles of the crystal by the magnetic or electric force, and that the results he obtained were not due to any inherent property of the crystallised body itself. If the force depended on the simple fact of crystallisation, then, as most bodies are capable of entering into the form of crystals, they should all be alike subject to the force; but, as already noticed, such does not appear to be universally the case.

In § 2,591, he remarks—"I cannot resist throwing forth another view of these phenomena, which may possibly be the true one. The lines of magnetic force may, perhaps, be assumed as in some degree resembling the rays of light, heat, &c., and may find difficulty in passing through bodies, and so be affected by them as light is affected [see our remarks on single and double refraction, at pp. 431, 432, *ante*]. They may, for instance, pass more freely when a crystalline body is interposed, or with less disturbance, through it in the direction of the magnecrystallic axis than in other directions. In that case, the position which the crystal takes in the magnetic field, with its magnecrystallic axis parallel to the lines of magnetic force, may be the position of no, or of least, resistance, and, therefore, the position of rest and stable equilibrium. All the diametral effects would agree with this view. Then just as the optic axis is to a ray of polarised light [see *ante*, p. 433, in respect to tourmaline, &c.]—namely, the direction in which it is not affected—so would the magnecrystallic force be to the lines of magnetic force. If such were the case, then, also, as the phenomena are developed in crystalline [crystal] bodies, we might hope for the discovery of a series of effects, dependent on retardation and influence of direction, parallel to the beautiful phenomena presented by light with similar bodies. In making this suggestion I do not forget the points of inertia and momentum; but such an idea as I can form of inertia does not exclude the preceding view as altogether irrational. I remember, too, that when a magnetic pole and a wire carrying an electric current are fastened together, so that one cannot turn without the other, if the one be made an axis, the other will revolve round and carry the first with it; and also, that if a magnet be floated in mercury, and a current sent down it, the magnet will revolve by the powers that are *within* its mass. With my imperfect mathematical knowledge, there seems as much difficulty in these notions as in the one I am supposing, and, therefore, I venture to put forth this idea. The hope of a polarised bundle of magnetic forces is enough, of itself, to make one work earnestly with such an object, though only in imagination, before us; and I may well say that no man, if he take industry, impartiality, and caution with him in his investigations of science, ever works experimentally in vain."

Faraday, in this description of his views of the cause of the phenomena of magnecrystallic force, refers to a subsequent section (§ 2,639) for a further exposition of the subject; remarking—

"Another supposition may be thrown out for consideration. I have already said that the assumption of a mere axial condition would account for the set without attraction or repulsion. Now, if we suppose it possible that the molecules should become polar in relation to the north and south poles of the magnet, but with no mutual relation amongst themselves, then the bismuth or other crystal might set as if induced with mere axial power; but it seems to me very improbable that the polarities of a given particle in a crystal should be subject to the influence of the polarities of the distant magnet-poles, and not also to the *like polarities* of the contiguous particles."

In the preceding remarks on the magnecrystallic force, metals alone have been considered. Plücker had found out that there seemed a relation between the optic axis of a crystal and magnetic action. At p. 435, *ante*, we have discussed what is meant by an optic axis, and have also stated that there are two classes of bodies—one possessing only one optic axis, and, consequently, called *uniaxial*, and others possessing two optical axes, and consequently termed *binaxial*. Plücker found that when a single-axis crystal was placed between the poles of a magnet, the axis of the crystal was repelled by each of those poles; that if a crystal have two optical axes (as, for example, quartz, &c.), each of the axes will be repelled by the poles of the magnet.

On this point Faraday remarks (§ 2,592)—"I have already referred to Plücker's beautiful discovery and results in reference to the repulsion of the optical axis of certain crystals by the magnet, and have distinguished them from my own, obtained with bismuth, antimony, and arsenic [see *ante*, p. 453], which are not cases of either repulsion or attraction—believing then, with Plücker, that the force there manifested is an optic axis force, exerted in the equatorial direction, and therefore existing in a direction

at right angles to that which produces the magnecrystallic phenomena.

"But the relations of *both* to crystalline [crystal] structure, and therefore to the force which confers that condition, are most evident. Other conditions as to position, set, and turning, also show that the two forces, so to say, have a very different relation to each other to that which exists between them and the magnetic or dia-magnetic force. As, therefore, the strong likeness on the one hand, and distinct separation on the other, is clearly indicated, I will endeavour to compare the two sets of effects, with the view of ascertaining whether the force excited in producing them is not identical." Faraday suspended a rhomb of calcareous (Iceland spar), with its optic axis horizontal, between the pointed poles of an electro-magnet; and found that when the magnet was excited, when the poles were as close as possible to the crystal, the latter set in an equatorial direction, and the optic axis coincided with magnetic axis; but if the poles were separated to the distance of half or three-quarters of an inch, the crystal (a rhomboid) turned through 90°, and set with the optic axis in the equatorial direction, and the greatest length was consequently axial, or coincident with the magnetic axis. On this he remarks—"In the first instance, the dia-magnetic force overcame the optic-axis force; in the second, the optic-axis force was the stronger of the two."

It is needless here to remark on the extreme delicacy of such investigations as these; but we may call attention to the fact, that a want of care in experimenting may lead to great errors. The two experiments just related were productive of precisely opposite results, through, apparently, the most trifling causes; and it frequently happens, in scientific research, that these apparent trifles, by observation, lead to new discoveries, and, by neglect, lead the investigators into a course exactly opposite to the truth.

Plücker arrived at the conclusion that a relation subsists between the forms of the elementary atoms of matter and magnetism; and, consequently, magnetism would, under such circumstances, give us a kind of insight into the molecular condition of bodies. But the assumption of the existence of "ultimate particles," or atoms, is often purely theoretical, and, of recent years, has been greatly disputed. By reference to p. 453, *ante*, the reader will find this question discussed very recently by Sir William Thomson. Dr. Tyndall's investigations led to other views. The result of his and Knoblauch's experiments was to show that magnetic and dia-magnetic phenomena became modified by change of mechanical condition. What we have related in respect to the researches of Faraday and Plücker has had reference to bodies in a crystal state; and all these conclusions, although differing in certain points, related to crystalline structure as an influencing cause. Tyndall reduced the substance to powder, and so *apparently* destroyed all symmetrical form; and, from a variety of experiments, he concluded, that "if the arrangement of the component particles of any body be such as to present different degrees of proximity in different directions, then the line of closest proximity, other circumstances being equal, will be that chosen by the respective forces for the exhibition of their greatest energy. If the mass be magnetic, this line will stand *axial;* if dia-magnetic, it will be *equatorial.*"

In Series XXIII. of his *Experimental Researches*, Faraday enters into the inquiry of the supposed polar or other conditions of dia-magnetic bodies. He introduces the subject by remarking—"Four years ago [1846] I suggested that all the phenomena presented by dia-magnetic bodies when subjected to the forces in the magnetic field, might be accounted for by assuming that they then possessed a polarity of the same in kind as, but the reverse in direction of, that acquired by iron, nickel, and ordinary magnetic bodies under the same circumstances. The view was received so favourably by Plücker, Reicsh, and others, and, above all, by Weber, that I had great hopes it would be confirmed; and although certain experiments of my own did not increase that hope, still my desire and expectation were in that direction."

Faraday undertook a great variety of experiments for the purpose of ascertaining whether or no such a polarity existed, in dia-magnetic bodies, as would be analogous to, but opposed in direction to, that of magnetic bodies.

We must here again make a few remarks on the term polarity, so as to explain its nature for the elucidation of this part of our subject. It is familiarly known to all our readers, that if the north pole of one magnet be presented to the north pole of another, the two will repel each other; whereas if a south pole be presented to a north pole, they will attract each other. Faraday desired to find whether or no a similar or analogous action obtained in dia-magnetic bodies.

We do not propose to occupy space unnecessarily in detailing the apparatus, methods, &c., which Faraday adopted in this inquiry; for he obtained results different to, or negativing those of Weber, and therefore opposed to his first expectations; and to this must be added the fact that Dr. Tyndall has since proved the existence of such polarity. We therefore only quote the conclusion at which Faraday arrived.

"Finally, I am obliged to say that I can find no experimental evidence to support the hypothetical view of dia-magnetic polarity, either in my own experiments, or those of Weber, Reicsh, and others. I do not say that such a polarity does not exist; and I should think it possible that Weber, by far more delicate apparatus than mine, had obtained a trace of it, were it not that then he also would have certainly met with the far more powerful effects produced by copper, gold, silver, and the better-conducting dia-magnetics. * * * It appears to me, also, that as the magnetic polarity conferred by iron or nickel, in very small quantity and in unfavourable states, is far more readily indicated by its effect on an astatic needle, or by pointing

between the poles of a strong horse-shoe magnet, than by any such arrangement as mine, or Weber's, or Reicsh's, so dia-magnetic polarity would be much more easily distinguished in the same way, and that no indication of that polarity has as yet reached to the force and value of those already given by Brugmann and myself."

Dr. Tyndall, as already stated, arrived at different results. On his discoveries in the matter, Dr. Noad remarks—"A series of memoirs have been published by Von Feilitsch, in which he endeavoured to prove that dia-magnetic bodies possess a polarity the *same* as that of iron; and, in this uncertain state of the subject, some admirable experiments were undertaken by Dr. Tyndall, the results of which were laid before the physical section of the British Association at Liverpool, in 1854. That the repulsion of a dia-magnetic body depends not alone on the magnet operating on it, but upon the joint action of the magnet and dia-magnetic, is proved by the fact that the repulsive force increases, not simply in proportion to the strength of the magnet, but to the square of the strength. Tyndall confirms the observation of Reicsh, that the condition, whatever it may be, which is evoked in the bar of bismuth by one magnetic pole is neutralised by the other; that each pole evokes a condition peculiar to itself; for when a bar of that metal was suspended between the poles of two bar electro-magnets, it was repelled when the poles were alike, but remained motionless when the poles were of opposite names. The most perfect antithesis was observed in all cases between the deportment of a *normal* dia-magnetic bismuth (a bar in which the planes of principal cleavage are parallel to the length of the bar) and a bar of soft iron; the electric and magnetic forces that caused a deflection of the former from right to left, produced a deflection of the latter from left to right. The whole experiment seemed to justify the presumption, that whatever be the nature of the influences evoked in magnetic bodies by the action of currents or magnets, or of both combined, to an influence of the same nature, but antithetical in its manner of distribution, the deportment of dia-magnetic bodies is to be referred."

"The following experiment is described by Tyndall, as pointing to the conclusion that, whatever the ideal magnetic distribution in iron may be, a precisely opposite distribution occurs in bismuth; or, in other words, that the dia-magnetic force is a polar force, but that the polarity is the reverse of magnetic polarity. Two helices were so placed that the ends of the soft iron cores which fitted into them were about six inches apart from centre to centre; the helices were at opposite ends of the planes which touched the ends of the cores. A helix of copper wire was introduced, and within it a bismuth bar $6\frac{1}{2}$ inches long, and $\frac{4}{10}$ths of an inch in diameter, was freely suspended, so that the ends of the bar were opposite to those of the soft iron cores. A current being sent through the helix, if the bismuth bar within it were excited by the current, it was probable that the nature of the excitement would manifest itself in the action of the magnets upon the dia-magnetic body. By working delicately, the utmost mastery was obtained over the suspended bismuth; when the current through the helix flowed in a certain direction, the ends of the dia-magnetic bar were repelled by the electro-magnets; when the current flowing through the helix was reversed, the same ends were attracted by the magnet. The same effect was obtained when, instead of reversing the helix current, the polarity of the two magnets was reversed. On comparing the deflections with those of soft iron, it was found that they were *perfectly antithetical.* The excitement which caused the ends of the iron bar to be attracted, caused the ends of the bismuth bar to be repelled; while the excitement which caused the ends of the iron bar to be repelled, caused those of the bismuth bar to be attracted.

"If it be true that the polarity of the bismuth bar is the reverse of magnetic polarity, its two ends must, when the current circulates round it, be in different states; but if this be the case, then, if we make the two poles acting on the ends of the bar *alike*, we ought to have attraction at one end and repulsion at the other; the result of these opposing actions being, that the bar must remain undeflected. Tyndall made this experiment, and the result was in accordance with the conclusion. Two magnets, with poles of the same name, were brought to bear on a bismuth bar, the direction of the force emanating from the two poles being the same—the repulsion of one end and the attraction of the other tended to deflect the bar; two other poles of the same name, but of opposite names to the former two, were then caused to act on the bar—*i. e.*, four magnets were employed—the two poles to the left being of the same name, and the two to the right of the opposite name. The bar was promptly deflected, thus corroborating the view that dia-magnetic bodies possess a polarity opposed to magnetic bodies.

"In the Bakerian Lecture for 1855, Dr. Tyndall re-investigated this interesting subject at great length, and adduced powerful experimental evidence in proof of the duality of dia-magnetic excitement and of dia-magnetic polarity. In experimenting with bismuth, the question of structure must be particularly attended to, for the setting of a bar of that metal between the magnetic poles will depend on the relation of the form of the mass to the planes of crystallisation. A bar of bismuth, whose planes of principal cleavage are throughout parallel to its length, suspended to the magnetic field with the same planes vertical, will set its longest dimension at right angles to the line joining the poles: this is the normal deportment of dia-magnetic bodies; and Tyndall, therefore, calls such a bar a *normal dia-magnetic bar.* On the other hand, a bar of compressed bismuth-dust, or a bar of bismuth whose principal planes of crystallisation are transverse to its length, will set axially in the magnetic field; such bars he calls *abnormal dia-magnetic bars.*

"Again, a bar of iron sets with its longest dimension from pole to pole; but a bar of compressed carbonate of iron-dust, whose shortest dimension coincides with the line of pressure, sets its length equatorially; the former may, therefore, be called a *normal paramagnetic bar*, and the latter an abnormal paramagnetic bar."

Here, for a moment, we must break off Dr. Noad's interesting description of the inquiry into dia-magnetic polarity by defining the word *paramagnetic*. In § 2,790, Series XXV., of Faraday's *Experimental Researches*, he remarks, in respect to this term—"The word *magnetic* ought to be general, and include *all* the phenomena and effects produced by the power. But then a word for the sub-division, opposed to the dia-magnetic class, is necessary. As the language of this branch of science may soon require general and careful changes, I, assisted by a kind friend, have thought that a word not selected with particular care might be provisionally useful; and as the magnetism of iron, nickel, and cobalt, when in the magnetic field, is like that of the earth as a whole, so that when rendered active they place themselves parallel to its axis, or lines of magnetic force, I have supposed that they and their similars (including oxygen now) might be called *paramagnetic bodies*, giving the following division :—

$$\text{Magnetic} \begin{cases} \text{Paramagnetic.} \\ \text{Dia-magnetic."} \end{cases}$$

Having thus defined the term paramagnetic, as first used by Faraday, and subsequently generally adopted by philosophers, we resume the thread of Dr. Noad's narrative of Tyndall's investigations into dia-magnetic polarity.

"Tyndall, in 1856, again investigated this interesting subject with an apparatus based on different principles to that which he had previously employed, and constructed (from a plan furnished by M. Weber) by M. Loyser, of Leipsic. The dia-magnetic bar, suitably excited, is permitted to act upon an astatic system of steel magnets, and from the deflection of this system the polarity of the bar is inferred. The instrument consisted essentially of two spirals of covered copper wire, about eighteen inches long, firmly attached to a massive slab of mahogany. The slab was attached by brass bolts to the solid masonry of the Royal Institution, so as to have the spirals in a vertical position. Above the spirals was a wooden wheel, with a grooved periphery, and below them a similar one. The wheels were united by an endless string, which communicated motion from one to the other. To this string the cylinders submitted to examination were attached; and, by turning the loose wheel by a suitable key, the cylinders could be caused to move up and down within the spirals. Two steel bar magnets were arranged astatically, connected by a rigid brass junction, and so suspended that the magnets were in a horizontal plane. The two magnets had the two spirals between them, their poles being opposite the centres of the spirals. When, therefore, a current was sent through the spirals, it excited no more action upon the magnets than the central or neutral point would do. If the bars within the spiral were perfectly central, they also would present their neutral points to the suspended magnets, and hence exert no action upon them. But if the key be so turned that the two ends of the dia-magnetic bars should act upon the magnets, then, if these bars be polar, the intensity and character of their polarity would be indicated by the deflection of the magnets; hence, not only was the action of the earth neutralised, but a turning force was brought to bear upon the suspended system four times that which would come into play if only a single spiral and a single pole had been made use of. The instrument was enclosed on all sides to prevent the action of air-currents; the magnets had a mirror attached to them, which moved as they moved, and which were observed by means of a telescope and scale, placed at a distance of about ten feet from the instrument.

"When cylinders of bismuth, copper, antimony, heavy glass, marble, and many other substances [dia-magnetics] were submitted to experiment with this apparatus, very marked deflections were produced. We quote one particular experiment, performed in the presence of Faraday, De la Rive, and Marcet. The bismuth cylinders were three inches long, and 0·7 of an inch in diameter, and were chemically pure. A current from a single cell of Grove's battery being caused to circulate in the helices, the cylinders remaining in their centres, the cross-wires of the telegraph cut the number 650 on the scale. Turning the lower wheel of the apparatus, so as to raise the left-hand cylinder and depress the right-hand one, the magnet promptly moved, and, after some oscillations, took up a new position of equilibrium—the cross-wire of the telescope then cutting 670 on the scale. Reversing the motion, so as to place the cylinders again central, the former position of 650 was reassumed; on turning the wheel further, so as to depress the left-hand cylinder and raise the right-hand one, the position of equilibrium of the magnet was at the number 630. Hence, by bringing the opposite ends of the cylinders to bear upon the astatic magnet, the motion was from smaller to greater numbers, the position of rest being then twenty divisions greater than when the bars were central. By bringing the other two opposite ends of the cylinders respectively to bear upon the magnet, the motion was from greater to smaller numbers, the position of rest being twenty divisions less than when the bars were central.

"When the current was caused to flow through the helices in the contrary direction, an opposite result was obtained. The following was the experiment:—The bismuth cylinder being in the centre of the helices, the cross-wire of the telescope cut the number 482 on the scale. Turning the wheel so as to raise the right-hand cylinder and depress the left, the cross-wire cut 468 on the telescope scale; reversing the motion, so as to place the cylinder again central, the former position of 482 was assumed; and, on turning further in the same direction, so as to

depress the left-hand cylinder and raise the right, the number indicated was 493. In this case, therefore, the first motion was from greater to smaller numbers, and the last from smaller to greater.

"In answer to the objection that has been urged against these experiments, that the deflections are due to induced currents aroused in the bismuth by its mechanical motion up and down within the spiral, Tyndall satisfactorily replied—1st. That the deflection produced is permanent, which could not be the case if the effect were due to induced currents, which vanish instantaneously. 2nd. If the effect were due to induction, it would be shown in the most exalted degree by the best conductors. Now antimony is less dia-magnetic than bismuth; but it is a better conductor. The deflection produced by it, however, shows that it is its dia-magnetic quality, and not its conductive quality, which is effective, the amount of deflection being less than that of bismuth. Copper is fifty times a better conductor than bismuth; but its dia-magnetic capacity is nearly *nil:* it produces no sensible action upon the magnets, which could not possibly be the case were the result due to induction. Both para-magnetic and dia-magnetic liquids have been included by Tyndall in this examination, and the polarity of both has been established by him."

It is evident, therefore, that although Faraday at first entirely failed to satisfy himself of the existence of dia-magnetic polarity, Tyndall and Weber have satisfactorily proved it to occur. As we have noticed, Faraday was himself witness of the fact. It is almost needless to point out, that, in reference to our accurate knowledge of the nature, causes, intensity, &c., of physical forces, the question of dia-magnetic polarity is one of the greatest interest. Polarity —that is, a determinate assumption of position in reference to force—is, at least, an evident quality of magnetism, heat, and light. In the magnet we have the polar direction of north and south: in electricity we have the equivalent of positive and negative. As already pointed out at p. 432, *ante*, light is capable of polarisation; and there can be little doubt, from our knowledge of dia-thermancy, in respect to heat, that this force is polarisable. In estimating the relation of nature's forces, the more we can assimilate the one to another, by producing proof of the existence of identical or analogous phenomena in each, the nearer do we approach to what we may call the harmonisation of the laws of nature. The great difficulty that opposes our progress in the study of natural phenomena, is that of arriving at the simplicity of the cause and operations. What can be more simple, for example, or more universal, than the attraction of gravitation. In all human-made machines, obstacles arise from their complexity. The parts are numerous, and each of them adds to the difficulty of producing a perfect arrangement. But when we investigate closely the phenomena that are presented to us in nature, no such complexity becomes apparent.

One power, force, or agent is sufficient for a thousand purposes. Take, for example, the force of heat, whatever its nature may be. Proceeding first, so far as our earth is concerned, from the sun, its rays are primarily absorbed by the atmosphere, which is, consequently, made capable of holding a large amount of water in a state of suspension; hence the phenomena of rain, dew, hail, and snow. The same rays of heat expand the air, and so cause it to be in perpetual motion, producing the effect popularly called wind. This results in a motion of the whole terrestrial atmosphere, producing all circumstances, so far as the air is concerned, conducive to the life of animals and vegetables, and the various changes that mineral bodies undergo antecedent to their conversion into animal and vegetable structures. The rays that pass through our atmosphere are absorbed by every substance on the face of the earth. These bodies store up the rays, and so promote germination, growth, &c., of animals and plants. Held latent by many bodies for thousands of years, they are at last educed, and afford us means of artificial light and heat. These are only a few of the effects out of thousands produced by *one* force; but they are sufficient to illustrate the point that, in nature, simplicity of action is a great characteristic.

Now, returning to the subject in hand—the polarity of dia-magnetic bodies—at first sight the question is not one of apparently great interest; but viewing it in its relations to magnetism generally in the first instance, and correlatively to light, heat, and electricity, it is one of paramount interest. The fact of the polarity of dia-magnetic bodies, indeed, generalises dia-magnetism with other forms of force. If such a polarity did not exist we should have to class dia-magnetic phenomena *sui generis*, or, in other words, apart from the rest of nature's forces. Consequently, years might have elapsed before philosophers had found out the relation in this respect between dia-magnetics and magnetics, and many fruitless and wearisome researches might have been required, had not the discovery been made.

The value of such a discovery as dia-magnetism must not, and cannot, be at present estimated. In 1819-'20, who would have thought that Œrsted's experiment, illustrating the divergence of the magnetic needle by means of a voltaic current, would have had the astonishing results that since have accrued. Then, and for many years afterwards, it was simply treated as a very interesting philosophical experiment; but at the present day it has netted the whole civilised world with telegraphic wires. Not long after that discovery, Faraday's proof of the mutual relation of a magnetised body and an electrified wire, followed by the great discoveries of electro-magnetic and magneto-electric induction, gave us the power of utilising Œrsted's results; and also new methods of telegraphy, that have largely superseded the needle telegraph. Indeed, in our time, most telegraphic arrangements depend, for their construction and mode of use, on the discovery that Faraday made

in respect to the phenomena just mentioned. But Faraday, and all the philosophers in Europe or America, could never have imagined that those discoveries would have had such splendid results.

Arguing from these facts, therefore, we may safely predicate, that although the phenomena of dia-magnetism that have been described in the preceding pages, may have, at present, no apparent practical value, however great their scientific interest may be, we cannot doubt but that, at some future day, results of great importance will arise. Nothing has been made in vain. There is not an occurrence, quality, condition, or other affection of matter and force that has what we may call an unimportance. Our daily-accumulated experience proves this. Half a century ago, gas, steam, electro-telegraphy, electro-metallurgy, photography, and a host of other applications of nature's forces, were either barely known or entirely strangers to us. But as the disposition to scientific inquiry extended, since the days of Sir Humphry Davy, each of these cropped out of the storehouse of nature. They have added to our national, commercial, and social prosperity; they have been intellectual and physical sources of advancement; and, in a precisely similar manner, we may expect that each accession of a further knowledge of scientific truth will be attended by similarly beneficial results.

Hitherto we have only treated on the magnetic affections—paramagnetic or dia-magnetic—in respect to solids and liquids; but a most interesting series of phenomena becomes apparent in connection with gases and flame.

Series XXV. of Faraday's *Researches* is devoted to the consideration of the magnetic affection of gases. He observes, at the commencement of this series—"Bancalari first showed that flame was dia-magnetic. The effect, as I proved, was due chiefly to the heated state of the gaseous portion of the flame; but besides that, it appeared that, at common temperatures, dia-magnetic phenomena could be exhibited in gases; and also, that, in their production, the gases differed much one from another; so that, taking common air, for instance, as a standard, nitrogen and many other gases were strongly dia-magnetic in relation to it, whilst oxygen took on the appearance of a magnetic body; for *they* were repelled from, while *it* was *attracted to*, the place of maximum force in the magnetic field."

But here Faraday refers to the results of experiments that he tried in 1847, three years antecedent to the date of this series (1850). These results were published in the *Philosophical Magazine* of the first-named year, accompanied by a letter from Professor Zantedeschi, giving an account of what Bancalari had attained.

In this letter, Zantedeschi states that, on the flame of a lamp being interposed between the poles of an electro-magnet, immediately the latter was put into action by the voltaic current, the flame was at once acted on. The following is his own description of the result:—

"I have constantly observed repulsion in the act of closing the circle [circuit], which lasted the whole time that the magnetism was kept up; and when in the act of opening the circle [circuit], I saw the flame return to its primitive position. Well satisfied with having in this manner confirmed this important fact, I applied myself to the study of the phenomena, and found—

"1. That this happens with contacts of both solid and hollow soft iron; whereupon I abandoned my suspicion that the movement of the flame was attributable to currents of air. I convinced myself that it was an immediate action of the magnetism upon the flame—a fact of the greatest importance to science.

"2. That the repulsion, when it is quite distinct, and the flame quite pure, and terminated in a well-shaped top, is accompanied by depression; repulsion and depression are simultaneously observed at the closing of the circle [circuit]; the return of the flame, and rising of it at the opening of the circle [circuit].

"3. That, *ceteris paribus*, the greatest effect takes place when the flame is touching the convex of the magnetic curves, indicated by iron-filings.

"4. That the action is null when the flame is placed in the centre of the interval which separates the two contacts.

"5. That in the manifestation of the effects stated above, it is not necessary for the contacts to be entirely separated; they may be placed at an angle, and touch at two corners; the flame placed within the base of this triangle generally manifests the two phenomena indicated.

"6. That there is a certain mass of the contact (or keeper pieces) which is the most efficacious: beyond a limit, which can be shown by experiment, increase of mass causes a diminution of the effect.

"7. That the movements of the flame increase with the number of pairs of the battery plates. With one pair the effect was not perceptible." He shows how, by a gradual increase of the number of plates employed, he obtained increased results.

Having received this interesting piece of scientific news, Faraday at once set about examining the phenomena. He remarks—"I soon verified the chief results of the dia-magnetic affection of flame, and scarcely know how I could have failed to observe the effects years ago." He employed the electro-magnet that he had used for his early experiments on the magnetisation of light, described at p. 456, *ante*. "The two terminal pieces [keepers] of iron forming the vertical magnetic poles were each 1·7 inch square, and 6 inches long; but the ends were shaped to a form approaching that of a cone, of which the sides had an angle of about 100°, and the axis of which was horizontal, and in the upper surface of the pieces of iron. The apex of each end was rounded, nearly a tenth of an inch of the cone being in this way removed. When these terminations were brought near to each other, they gave a powerful effect in the magnetic field; as the axial line of magnetic force was of course horizontal, and on a level

nearly with the upper surface of the bars. I have found this form exceedingly advantageous in a great variety of experiments."

For the assistance of our readers we give an illustration of what Faraday used. In the following cut *a a* represent the two arms of an

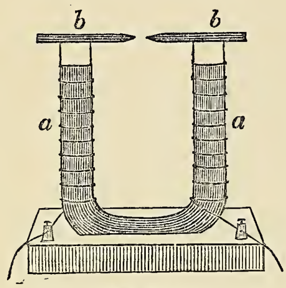


Fig. 260.

electro-magnet, and *b b* the keeper just described.

"Whilst the flame of a wax taper was held near the axial line, but on one side or the other, about one-third of the flame rising above the level of the upper surface of the poles, as soon as the magnetic force was on, the flame was affected, and receded from the axial line, moving equatorially, until it took an inclined position, as if a gentle wind was causing its deflection from an upright position—an effect which ceased the instant the magnetism was removed.

"The effect was not instantaneous, but rose gradually to a maximum. It ceased very quickly when the magnetism was removed. The progressive increase is due to the gradual production of currents in the air about the magnetic field, which tend to be, and are, formed on the assumption of the magnetic conditions in the presence of the flame.

"When the flame was placed so as to rise truly across the magnetic axis, the effect of the magnetism was to compress the flame between the points of the poles (see cut), making it recede in the direction of the axial line from the poles towards the middle transverse plane, and also to shorten the top of the flame. At the same time the top and sides of the compressed part turned more widely, because of two streams of air which set in from the poles on each directly against the flame, and then passed out with it in the equatorial direction. But there was, at the same time, a repulsion or recession of the parts of the flame from the axial line; for those portions which were below did not ascend so quickly as before; and, in ascending, they also passed off in an inclined and equatorial direction.

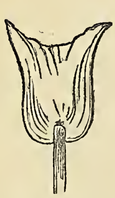


Fig. 261.

"On raising the flame a little more, the effect of the magnetic force was to increase the intensity of the results just described, and the flame actually became of a fish-tail shape, disposed across the magnetic axis (illustrated in the following cut).

"If the flame was raised until about two-thirds of it were above the level of the axial line, and the poles approached so near to each other (about one-third of an inch) that they began to cool and compress the part of the flame at the axial line, yet without interfering with its rising truly between them; then, on rendering the magnet active, the flame became more and more compressed and shortened; and, as the effects arose to a maximum, the top at last descended, and the flame no more rose between the magnetic poles, but spread out right and left, on each side of the axial line, producing a double flame with the long tongues (see following cut).

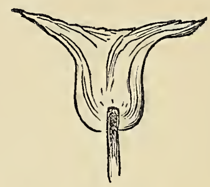


Fig. 262.

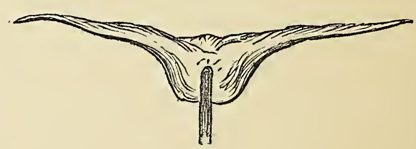


Fig. 263.

"This flame was very bright along the upper extended forked edge, being there invigorated by a current of air, which *descended* between the poles on to the flame at this part, and, in fact, drove it away in the equatorial direction.

"When the magnet was thrown out of action, the flame resumed its ordinary upright form between the poles at once, being depressed and re-divided again by the renewal of the magnetic action.

"When a small flame, only about one-third of an inch high, was placed between the poles, the magnetic force instantly flattened it into an equatorial disc.

"If a ball of cotton, about the size of a nut, be bound up by a wire, soaked in ether, and inflamed, it will give a flame five or six inches high. This large flame rises freely and naturally between the poles; but as soon as the magnet is rendered active, it divides and passes off into two flames, the one on one side, and the other on the other side of the axial line.

"I verified the results obtained by M. Zantedeschi with different flames, and found those produced by alcohol, ether, coal-gas, hydrogen, sulphur, phosphorus, and camphor, were all affected in the same manner, though not, apparently, with equal strength. The brightest flames appeared to be most affected.

"The chief results may be shown in a manner in some respects still more striking and instructive than those obtained with flame by using a smoking taper. A taper made of wax coloured

green by verdigris, if suffered to burn upright for a minute, and then blown out, will usually leave a wick with a spark of fire upon the top of it. The subdued combustion will, however, still go on, even for an hour or more, sending up a thin dense stream of smoke, which, in a quiet atmosphere, will rise vertically for six or eight inches ; and in a moving atmosphere, will show every change of its motion, both as to direction and intensity. When the taper is held beneath the poles, so that the stream of smoke passes a little on one side of the axial line, the stream is scarcely affected by the power of the magnet, the taper being three or four inches below the poles; but if the taper be raised so that the coal is not more than an inch below the axial line, the stream of smoke is much more affected, being bent outwards ; and if it be brought still higher, there is a point at which the smoke leaves the taper-wick, even in a horizontal direction, to go equatorially. If the taper be held so that the smoke-stream passes *through* the axial line, and then the distances be varied as before, there is little or no sensible effect when the wick is four inches below ; but being raised, as soon as the *warm* part of the stream is between the poles it tends to divide ; and when the ignited wick is about an inch below the axial line, the smoke rises vertically in one column until about two-thirds of that distance is passed over, and then it divides, going right and left, leaving the space between the poles clear. As the taper is slowly raised, the division of the smoke descends, taking place lower down, until it occurs upon the wick at the distances of 0·4 or 0·5 of an inch below the axial line. If the taper be raised still more, the magnetic effect is so great, as not only to divide the stream, but to make it descend on each side of the ignited wick, producing a form like the letter W ; and, at the same time, the top of the burning wick is greatly brightened by the stream of air that is impelled downwards upon it. In this experiment the magnetic poles should be about 0·25 of an inch apart.

"A piece of burning amadou [German tinder], or the end of a splinter of wood, produced the same effect.

"By means of a like small spark and a stream of smoke, I have even rendered evident the power of an ordinary magnet. The magnet was a good one, and the poles were close to each other, and conical in form.

"Before leaving this description of the general phenomena, and proceeding to a consideration of the principle of magnetic action concerned in it, I may say that a single pole of the magnet produces similar effects upon flame and smoke, but that they are much less striking and observable.

"Though the effect be so manifest in flame, it is not, at first sight, evident what is the chief cause or causes of the result. The *heat* of the flame is the most apparent and probable condition; but there are other circumstances which may be equally or more influential. Chemical action is going on at the time; solid matter which, known to be dia-magnetic, exists in several of the flames used; and a great difference exists between the matter of the flame and the surrounding air. Now any or all of these circumstances of temperature, chemical action, solidity of part of the matter, and differential composition in respect to the surrounding air, may occur in producing or influencing the result.

"I placed the wires of an electrometer, and also of a galvanometer, in various parts of the affected flame, but could not procure any indications of the evolution of electricity by any action on the instruments.

"I examined the neighbourhood of the axial line as to the existence of any current in the air when there was no flame or heat there, using the visible fumes produced when little pellets of paper, dipped in strong solutions of ammonia and muriatic acid, were held near each other; and although I found that a stream of such smoke was feebly affected by the magnetic power, yet I was satisfied that there was no current or motion in the common air, as such, between the poles. The smoke itself was feebly dia-magnetic, due, I believe, to the solid particles in it.

"But when flame or a glowing taper is used, strong currents are, under favourable circumstances, produced in the air. If the flame be between the poles, these currents take their course along the surface of the poles, which they leave at the opposite faces connected by the axial line, impinge on the opposite sides of the flame, and, feeding the flame, they make part of it, and proceed out equatorially. If the flame be driven asunder by the force of these currents, and retreat, the currents follow it; and so, when the flame is forked, the air which is between the poles forms a current, which sets from the poles downwards and sideways towards the flame. I do not mean that the air in every case travels along the surface of the poles, or along the axial lines, or even from between the poles; for, in the case of the glowing taper, held half an inch or so beneath the axial line, it is the cool air which is next nearest to the taper, and (generally) between the taper and the axial line, that falls with most force upon it. In fact, the movements of the parts of air and flame are due to a differential action. We shall presently see that the air is dia-magnetic, as well as flame or hot smoke—*i.e.*, that both tend to move from stronger to weaker places of magnetic force—but that hot air and flame are more so than cold or cooler air : so when flame and air, or air at different temperatures, exist at the same time within a space under the influence of magnetic forces differing in intensity of action, the hotter particles will tend to pass from stronger to weaker places of action, to be replaced by the colder particles ; the former, therefore, will have the effect of being repelled, and the currents that are set up are produced by this action, combined with the mechanical force or current possessed by the flame in its ordinary relation to the atmosphere.

"It will be evident that I have considered flame only a particular case of a general law.

It is a most important and beautiful one, and it has given us this discovery of dia-magnetism in gaseous bodies ; but it is a complicated one, as I shall now proceed to show by analysing some of its ordinary conditions, and separating their effects.

"For the purpose of examining the effect of heat alone in conducing to the dia-magnetic condition of flame, a small helix of fine platina wire was attached to two stronger wires of copper, so that the helix could be placed in any given position as regarded the magnetic poles, and at the same time be ignited by a voltaic battery. In this manner it was substituted for the burning taper, and gave a beautiful, highly heated current of air, unchanged in its chemical condition. When the helix was placed directly under the axial line, the hot air rose up between the poles freely, being rendered evident above by a thermometer, or by burning the finger, or even scorching paper ; but as soon as the magnet was rendered active, the hot air divided into a double stream, and was found ascending on the two sides of the axial line ; but a descending current was formed between the poles, flowing downward towards the helix and the hot air, which rose and passed off sideways from it.

"It is, therefore, perfectly manifest that hot air is dia-magnetic in relation to, or more dia-magnetic than, cold air ; and from this fact I concluded, that, by cooling the air below the natural temperature, I should cause it to approach the magnetic axis, or appear to be magnetic in relation to ordinary air. I had a little apparatus made, in which a vertical tube, delivering air, was passed through a vessel containing a frigorific mixture, the latter being clothed with flannel, that the external air should not be cooled and so invade the whole of the magnetic field. The central current of cold air was directed downward, a little on one side of the axial line, and, falling into a tube containing a delicate air thermometer, there showed its effect. On rendering the magnet active, this effect, however, ceased, and the thermometer rose ; but on bringing the latter under the axial line, it again fell, showing that the cold current of air had been drawn inward, or attracted toward the axial line—*i. e.*, had been rendered magnetic in relation to air at common temperatures, or less dia-magnetic than it. The lower temperature was 0° Fah. The effect was but small, still it was distinct.

"The effect of heat upon air, in so greatly increasing its dia-magnetic condition, is very remarkable. It is not, I think, at all probable that the mere effect of expanding the air is the cause of the change in its condition, because one would be led to expect that a certain bulk of expanded air would be less sensible, in its dia-magnetic effects, than an equal bulk of denser air ; just as one would anticipate that a vacuum would present no magnetic nor dia-magnetic effects whatever, but be at the zero point between two classes of bodies. [See table of magnetics and dia-magnetics, given at pp. 449, 450, *ante.*] It is certainly true, that if the air were a body belonging to the magnetic class, then its expansion being equivalent to dilution, would make it seem dia-magnetic in relation to ordinary air ; but that, I think, is not likely to be the case, as will be seen by the results described further on, in reference to oxygen and nitrogen.

"If the power conferred by heat is a direct consequence, and proportionate to the temperature, then it gives a very remarkable character to gases and vapours, which, as we shall see hereafter, possess it in common. In my former experiments I heated various dia-magnetic bodies, but could not perceive that their dia-magnetic force was at all increased or affected by the temperature given to them. I have, again, submitted small cylinders of copper and silver to the action of a single pole, at common temperatures, and at a red heat, with the same result. At present, therefore, the gaseous and vaporous bodies seem to be strikingly distinguished by the powerful effect which heat has in increasing their dia-magnetic condition.

"As all the experiments, whether on flame, smoke, or air, seemed to show that air had a distinct magnetic relation, which, though highly affected by the temperature, still belonged to it at all temperatures ; so it was a probable conclusion that other gaseous or vaporous bodies would be dia-magnetic or magnetic, and that they would differ from each other even at common or equal temperatures. I proceeded, therefore, to examine them, delivering streams of each into the air, in the first instance, by fit apparatus and arrangements, and examining the course taken by these streams in passing across the magnetic field, the magnetic force being either induced or not at the time.

"In delivering the various streams, I sometimes introduced the gases into a globe with a mouth, and also a tubular spout, and then poured the gas out of the spout upwards or downwards, according as it was lighter or heavier than air. At other times, as with muriatic [hydrochloric] acid or ammonia, I delivered the streams from the mouth of the retort. But as it is very important not to deluge the magnetic field with a quantity of invisible gas, I devised the following arrangement, which answered well for all the gases not soluble in water :—A Woulfe's bottle was chosen, having three apertures at the top ; a wide tube was fixed into one aperture, descending within the bottle to the bottom, and being open above and below ; by this any water could be poured into the bottle, and employed to displace the gas previously within it. Another aperture was closed by a stopper, and the third aperture had an external tube, with a stopcock fixed in it, to conduct the gas to any place desired. To expel the gas and send it forward, a cistern of water was placed above the bottle, and its cock so plugged by a splinter of wood that, when full open, it delivered only twelve cubic inches of fluid in a minute. This stream of water being directed into one aperture, and the delivering aperture for the gas being open, twelve cubic inches of any gas within the Woulfe's bottle were delivered in a minute of time ; and this I

found an excellent proportion for our magnet and apparatus in carrying out the details of this investigation.

"With respect to the delivery of this gas at the magnetic poles, a piece of glass tube was bent into such a shape as to permit it to be held by a clamp on the stage of the magnet, so that it could be easily slipped backward and forward, or to one side, and so its vertical part be placed anywhere below the axial line. The aperture at this end was about one-eighth of an inch internal diameter. In the horizontal part, near the angle, was placed a piece of bibulous paper, moistened with a strong solution of muriatic acid when necessary. The horizontal part of the tube was connected and disconnected in a moment, when necessary, with the delivering tube of the gas-bottle, by a short piece of vulcanised india-rubber tube. If the gas to be employed as a stream were heavier than the surrounding medium, then the glass tube, instead of having the form delineated above, was so bent as to deliver its stream downwards, and over the axial line. In this manner currents of different gases could be delivered perfectly steady, and under perfect command.

"The next point was to detect and trace the course of these streams. A little ammonia vapour, delivered near the magnetic field, did this in some degree, but was not satisfactory; for, in the first place, the little cloud of muriate of ammonia particles formed, is of itself dia-magnetic; and, further, the tranquil condition of the air in the magnetic field was then too much disturbed. Catch-tubes were therefore arranged, consisting of tubes of thin glass, about the size and length of a finger, open at both ends, and fixed upon little stands, so that they could be adjusted either over or under the magnetic poles at pleasure. When they were over the poles, I generally had three at once; one over the axial line, and one at each side. When they were under the poles, the lower end was turned up a little, for the purpose of facilitating observation there.

"The gas delivered at the poles, as already described, contained a little muriatic acid (obtained from the solution in the paper), but not enough to render it visible. To make manifest up which catch-tube it passed, a little piece of bibulous paper, folded and bound round, and suspended by a copper wire, was dipped in the solution of ammonia, and hung in each of the tubes. It was then evident at once, by the visible fume formed at the top of one of the tubes, whether the gas delivered below passed up the one or the other tube, and which; and yet the gas was perfectly clear and transparent as it passed by the place of magnetic action." By means of thin plates of mica, a kind of sheltering arrangement was made, so as to preserve the air about the magnetic poles or field from disturbance. The following is Faraday's account of the results he obtained:—

"In the first place air was sent in under this arrangement, the stream being directed by the axial line. It made itself visible in the catch-tube above by the smoke produced; but whether the magnet was active or not, its course was the same, showing that, so far, the apparatus worked well, and did not of itself cause any erroneous indications.

"*Nitrogen.*—This gas was sent from below upwards, and passed directly by the axial line into the catch-tube above; but when the magnet was made active the stream was affected, and though not stopped in the middle catch-tube, part appeared in the side tubes. The jet was then arranged a little on one side of the axial line, so that, without the magnetic action, it still ascended and went up the middle catch-tube; when the magnetic action was brought on it was clearly affected. The nitrogen was, in fact, manifestly dia-magnetic in relation to common air when both were at the same temperature; but as four-fifths of the atmosphere consist of nitrogen, it seemed very evident, from the result, that nitrogen and oxygen must be very different from each other in their magnetic relations.

"*Oxygen.*—A stream of oxygen was sent down through air between the poles. When there was no magnetic action it descended vertically; and when the magnetic action was on it appeared to do the same; at all events it did not pass off equatorially. But as there was reason, from the above experiments with nitrogen, to expect that oxygen would appear, not dia-magnetic, but magnetic in air, the place of the stream was changed, and made to be on one side of the axial line. In this case it fell perfectly well at first into a catch-tube placed beneath; but as soon as the magnet was rendered active the stream was deflected, being drawn towards the axial line, and fell into another catch-tube placed there to receive it. So oxygen appears to be magnetic in common air;" or, perhaps, less dia-magnetic than common air.

"*Hydrogen.*—This gas proved to be clearly, and even strongly, dia-magnetic. * * * Its dia-magnetic state shows, in a striking point of view, that gases, like solids, have peculiar and distinctive degrees of dia-magnetic force.

"*Carbonic Acid.*—This gas made a beautiful experiment. The stream was delivered downwards, a little on one side of the axial line; a catch-tube was placed a little further out, so that the stream should fall clear of it as long as there was no activity in the magnet. But on rendering the magnet efficient, the stream left its vertical direction, passed equatorially, and fell into the catch-tube; and by looking horizontally, could be seen flowing out at its lower extremity like water, and falling away through the air. Again, the magnet was thrown out of action, and a glass with lime-water placed beneath the lower end of the catch-tube; no carbonic acid appeared there, though the fluid in the glass was continually stirred; but the instant the magnet was excited, the carbonic acid appeared in the catch-tube, fell into the glass, and made the lime-water turbid. Carbonic acid gas, therefore, is dia-magnetic in the air."

Carbonic Oxide.—This gas Faraday considered to be much more dia-magnetic than carbonic acid gas.

Nitrous Oxide.—This gas was moderately, but clearly, dia-magnetic in air. On this point Faraday remarks, that "much interest belongs to this and the other compounds of nitrogen and oxygen, both because they contain the same elements as air, and because of the relations of nitrogen and oxygen separately;" that is, in a state of non-combination.

Nitric Oxide was so slightly dia-magnetic as to be with great difficulty detected. *Nitrous acid gas* was similarly difficult to observe, but appeared dia-magnetic.

Olefiant gas and *London coal-gas* were both dia-magnetic.

Sulphurous acid, muriatic or *hydrochloric acid*, with *hydrodic acid*, were all dia-magnetic; and so were *ammonia, chlorine, iodine, bromine,* and *cyanogen.*

Faraday remarks—"Taking air as the standard of comparison, it is very striking to observe that, much as gases appear to differ one from another in the degree of their dia-magnetic condition, there are very few that are not more dia-magnetic than it; and when the investigation is carried forward into the relation of the two chief constituents of air, oxygen and nitrogen, it is still more striking to observe the very low condition of oxygen, which, in fact, is the cause of the very low condition of air. Of all the vapours and gases yet tried, oxygen seems to be that which has the least dia-magnetic force.

"All the compounds of oxygen and nitrogen seemed to show the influence of the presence of oxygen." Still Faraday, for the moment, came to the conclusion that oxygen is dia-magnetic, but that the addition of oxygen to another body rendered the latter less dia-magnetic than when separate. "But the truth may be, not that oxygen is really magnetic, but that a compound body possesses a specific dia-magnetic force which is not equal to the sum of the forces of its particles," or constituents. He adds—

"It is very difficult to form more than a mere guess at the relative degree of dia-magnetic force possessed by different gaseous bodies when they are examined only in air, because of the many circumstances which tend to confuse the results. First there is the invisibility of the gas, which deprives us of the power of adjusting by sight so as to obtain the best effect: then there is the difference of gravity; for if a gas ascend or descend in a vapour stream, it may seem less deflected than another flowing more slowly, though it be more dia-magnetic; and as to gases nearly of the specific gravity of air, whether more or less dia-magnetic, they are almost entirely dispersed in different directions, so that little only enters the catch-tube. Another modifying circumstance is the distance of the aperture delivering the gas from the axial line, which, to obtain the maximum effect, ought to vary with the gravity of the gases and their dia-magnetic force. Again, it is important that the magnetic field be not filled with the gas to be examined, and that, generally speaking, only a moderate stream be employed; which, however, must depend again on the specific gravity."

Faraday, considering that the only correct way of comparing two gases together is to experiment with them one in the other, constructed a simple arrangement in the shape of a trough, which was kept constantly full of carbonic acid gas; this was in addition to the arrangements already described, and which were retained, the object being to have a medium of carbonic acid in place of common air in the magnetic field of action. By this mode of experimenting, he found that *air* passed axially, being less dia-magnetic than carbonic acid gas; *oxygen* passed to the magnetic axis; *nitrogen* went equatorially, being therefore dia-magnetic even in carbonic acid gas; *hydrogen, coal-gas, olefiant gas, hydrochloric acid gas,* and *ammonia,* passed equatorially, and were dia-magnetic in carbonic acid gas; *carbonic oxide* behaved similarly; whilst *nitrous oxide* appeared to be only slightly dia-magnetic to carbonic acid.

He then varied the experiment by employing hydrogen and coal-gas, as gases lighter than air, as the medium, in place of carbonic acid gas. He found that oxygen had the appearance of being strongly magnetic in coal-gas, "passing with great impetuosity to the magnetic axis, and clinging about it; and if much muriate of ammonia fume were purposely formed at the time, it was carried by the oxygen to the magnetic field with such force as to hide the ends of the magnetic poles. If then the magnetic action were suspended for a moment, this cloud descended by its gravity; but being quite below the poles, if the magnet were again rendered active, the oxygen cloud immediately started up and took its former place. The attraction of iron-filings to a magnetic pole is not more striking than the appearances presented by oxygen under these circumstances."

He found *nitrogen* clearly dia-magnetic in coal-gas, as were also *olefiant, carbonic oxide, and carbonic acid gases.* In hydrogen, *air* seemed to have a similar amount of dia-magnetic force to that gas. *Nitrogen* was strikingly dia-magnetic, and oxygen equally as magnetic in hydrogen. *Nitrous oxide* was clearly dia-magnetic in hydrogen, and gave rise to a very beautiful result in consequence of its following the oxygen; for, at the beginning of the experiment, the little oxygen contained in the conducting-tube passed axially; but the instant this was expelled, and the nitrous oxide issued forth, the stream changed its direction, and passed off dia-magnetically in the most striking manner. *Nitric acid* was magnetic in relation to hydrogen. *Ammonia,* dia-magnetic; as were also *carbonic oxide, carbonic acid,* and *olefiant* gases; whilst *chlorine* and *hydrochloric acid* were slightly dia-magnetic.

He then proceeded to determine the effect of an increase of temperature, comparing a hot gas in a medium of the same gas at ordinary temperatures. Hot oxygen was dia-magnetic to cold oxygen, as was also hot carbonic acid in cold carbonic acid. Generally he found the effect of heat to be that of rendering all the

gases more highly dia-magnetic than they are at ordinary temperatures, whether in respect to the relations of each gas with itself, or with others at differing temperatures. He concludes this interesting subject, so far as the paper from which we have quoted is concerned, by the following general remarks :—

"As air, at different temperatures, has different dia-magnetic relations ; and as the atmosphere is at different temperatures in the upper and lower strata, such conditions may have some general influence and effect upon its final motion and action, subject as it is continually to the magnetic influence of the earth."

So far for Faraday's experiments in confirmation of those made by Zantedeschi and Bancalari. We now turn briefly to relate further results that he obtained, and described in the Series XXV. of his *Experimental Researches.* But, before doing so, a few remarks may be made on the lessons taught to the scientific student by the quotation just given.

Familiar as we have been with Faraday's experimental researches, in his laboratory, the lecture-room, and as described in his works, we could scarcely point to any of them that are exceeded in painstaking and carefulness beyond those just described. We may especially notice the extreme care evinced in those researches in regard to the detection of the direction of the gases he experimented on. Beginning with the comparatively crude results obtained by Bancalari and Zantedeschi, he confirms what they professed to have discovered; but simultaneously extends his own previously-made discoveries by showing the dia-magnetic nature of various gases ; the relative and absolute force of each; the action of various media modifying that exhibition of force; and, lastly, the modifying power of heat, through the action of which the same gas occupies a different dia-magnetic relation in respect to itself at varying temperatures. The extremely narrow circles in which such discoveries are studied and understood, prevent a full and general appreciation of the genius and sagacity of Faraday. The beauty of many of his discoveries is to be found in their extreme simplicity. But this quality is at once difficult to be recognised, studied, and appreciated. As we have frequently pointed out in this work, all man can do, in studying the laws of nature, is to gradually arrive, by slow progress, to understand their unity and simplicity. Nothing is more difficult for the beginner than the study of Euclid. Yet to those who have mastered the details of his geometry, the difficulty occurs as to the reason why any person cannot progress in its study. Certainly, but in a minor degree, we may ascribe to Faraday, in his *Experimental Researches*, a similar simplicity, ease, and perfection of demonstration, and close inductive reasoning. If we may so say, Faraday was the Euclid of modern experimental philosophy.

Having got a kind of clue to the dia-magnetic relationship of various gases during the prosecution of the inquiries already detailed in connection with flame and gases, Faraday proceeded still further to push his investigations, and to arrive at broader or deeper results. In the preceding pages, we have seen how he proved the universal action of magnetism, either paramagnetically or dia-magnetically, in respect to solids and liquids. Both of these are tangible substances. They can be seen by the eye, handled, directed with the greatest ease ; and, in fact, present but trifling difficulties in an experimental point of view. Not so with gases. As a rule they are invisible to the eye ; only a few, as chlorine, hydrochloric acid gas, ammonia, binoxide of nitrogen, and a few others, being capable, by colour or chemical tests, of being recognised in their passage through air, tubes, or other usual media. The difficulty of investigating their dia-magnetic character, from these and other circumstances, would have been all but insuperable, except in the hands of such an experimentalist as Faraday. We have noticed with what an ingenious method he was enabled to trace the progress of each gas into the catch-tubes, and how successfully he carried out the simple but clever plan. In the following description of his further investigations into the dia-magnetic or magnetic character of the gases, we shall not fail to perceive many remarkable repetitions of the exercise of the same ingenuity.

After recounting the results obtained by Bancalari in the magnetisation of flame, with his own just described, Faraday observes, in respect to them—"This effect, as I proved, was due chiefly to the heated state of gaseous portions of the flame ; but, besides that, it appeared that at common temperatures dia-magnetic phenomena could be exhibited by gases ; and that also, in their production, the gases differed very much from each other ; so that, taking common air, for instance, as a standard, nitrogen and many other gases were strongly dia-magnetic in relation to it, whilst oxygen took on the appearance of a magnetic body ; for *they* were repelled from, while *it* was attracted to, the place of maximum force in the magnetic field.

"Recalling the general law given respecting the action of magnetic and dia-magnetic forces—namely, that the former tend to go from weaker to stronger places, and the latter from stronger to weaker places of magnetic power—and applying it to such bodies as the gases, which are at the same time highly elastic, and easily changed in bulk by the super-addition of very small degrees of force, it would seem to follow that, if the particles of a dia-magnetic gas tended to go from strong to weak places of action, in consequence of the direct and immediate effect of the magnetic power on them, then such a gas should tend to become enlarged or expanded in the magnetic field. For the amount of power by which the particles would tend to recede from the axis of the magnetic field, would be added to the expansive force by which they before resisted the pressure of the atmosphere ; that pressure would, therefore, be in part sustained by the new force, and expansion would, of necessity, be the result. On the other hand, if a gas were magnetic (as, for instance, oxygen), then the force cast upon the

particles by such a direct and immediate action of the magnetic power upon them, would urge them *towards* the axis of the magnetic field, and so coinciding with, and being superadded to, the pressure of the atmosphere, would tend to cause contraction and diminution of bulk.

"If such supposititious cases were to prove true, we should then be able to arrive at the knowledge of the real zero point [see table of magnetics and dia-magnetics, given at pp. 452 and 453, *ante*], not amongst gases only, but amongst all bodies, and should be able to tell whether such a gas as oxygen were a magnetic or a dia-magnetic body; and also be able to range individual gases and other substances in their proper places [here Faraday means in reference to the paramagnetic and dia-magnetic characteristics]. And although I had originally endeavoured to ascertain whether there was any change of bulk in the air in the magnetic field, and found none, still Plücker's statement that he had obtained such an effect [see *Annales de Chemie*, 1850, vol. xxix., p. 134], and the great enlargement of knowledge respecting gases which since then we have acquired, relating to their dia-magnetic relations, and especially of the great difference which exists between them, encouraged me to proceed."

Faraday, however, in these investigations, found no expansion of gases by magnetism. Arranging an apparatus, by means of which a luminous image was viewed by a telescope, and attempting to act magnetically on the air in contact with a magnetic pole, he found "not the smallest change in either the character or place of the luminous image, * * * either on the making or the breaking of the contact between the voltaic battery and the magnetic wire." The telescope he employed was certainly powerful enough to have detected any such change, had it taken place, having been a fine refracting telescope belonging to Sir James Smith, with an aperture of three inches, and a focal length of forty-six inches. He also employed his powerful electro-magnet, excited by twenty pairs of Grove's battery.

Oxygen, nitrogen, hydrogen, and coal-gas were thus employed; but whether any one of these, or whether air itself was submitted to examination, when in contact with the active pole of a very powerful magnet, it did not appear to be either expanded or condensed to such a degree as to cause any sensible change in its refractive force. Considering that possibly only the thin layer of air coating the pole of the magnet might have been affected, and yet unobserved by him, he refined his arrangements, but with no positive result.

He next attempted to determine and compare the *volume* of air subjected to the magnetic force, before and after its subjection, and constructed an ingenious apparatus by which such an investigation could be accurately carried out. But in this, as in the preceding case, the results he obtained were negative, whether in regard to air, oxygen, nitrogen, carbonic acid, or nitrous oxide. On the results of these and other experiments, he remarks, § 2,750 :—

"I think that the experiments are, in every respect, sufficient to decide that these gases, whether they are considered as magnetic or dia-magnetic bodies, or whether they include bodies of both classes (for oxygen is in striking contrast to the rest), are not affected in volume by the magnetic force, whether in fields of equal power, or in places where the power is rapidly diminishing. I think this decision very important in relation to the true nature of the magnetic force, either as existing in, or acting upon, the particles of bodies; and as in the magnetic field, the force exhibits itself, not as a central, but as an axial power, so the further distinction of the phenomena into such as are related to the axial direction, and such as are related to or include the equatorial direction, is not unimportant; for they show that the particles do not tend to separate, either parallel to the lines of magnetic power, or in a direction perpendicular to those lines. Without the experiments the mind might have considered it very possible that one of these modes of expansion might have occurred, and not the other."

In reasoning on the cause of the dia-magnetic change of place, Faraday remarks on what he has called *differential magnetic action*, in respect to gases. "The dia-magnetic phenomena of gases, when considered as the differential result of the action of volumes of these bodies, may be produced and examined with ease by means of soap-bubbles containing them." He constructed a simple and ingenious apparatus, by means of which such soap-bubbles could be formed; regu-

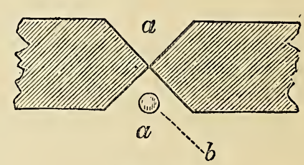


Fig. 264.

lating the quantity of water contained in the bubble with great care, so as not to introduce an element of error. The magnetic arrangement, in respect to the poles, was effected by turning down a piece of soft iron in such a manner, that an open space, *a a*, as seen in the above cut, should afford the field of action in respect to the electro-magnet, *b* being intended to represent the soap-bubble acted on. The bubbles were blown as near as possible of one size—about half an inch in diameter.

It will be easily seen that this mode of trying the dia-magnetic force of the different gases was necessarily far more complete than that already described, simply because, for all practical purposes, the gas became visible; that is, being enclosed in an external coat, the latter necessarily showed any position of the bubble, and, consequently, of the gas when submitted to magnetic action. As the result of these experiments, he remarks :—

"On blowing such a bottle with air in the dependent position, placing it in the angle of the double pole, on a level with the axial line [as

shown in the preceding cut], and then putting on the magnetic power by the use of twenty pairs of plates [Grove's battery], the bubble was deflected outward from the axial line (or equatorially) with a certain amount of force, and returned to its first position on the interruption of the electric current. The deflection was not great; and, being due to the water of the bubble, gave an indication of the amount of that effect to be used as a correction in experiments with other gases.

"Nitrogen in air, enclosed in a bubble, gave a very striking effect; showing its highly dia-magnetic character by strongly setting equatorially—keeping such a position with the greatest pertinacity so long as the magnetic force was kept in action."

Oxygen exhibited an entirely opposite character. "The effect was very impressive, the bubble being pulled inward or toward the axial line sharply and suddenly, exactly as if the oxygen were highly magnetic. The result was expected, being in accordance with the phenomena presented by oxygen and nitrogen in a former investigation of the dia-magnetic phenomena of these gases" (see *ante*, p. 468).

Bubbles of nitrous oxide and olefiant gas went outward, or dia-magnetically, proving the relation of these gases to air, and accordant with the results already described at the page just referred to. From these experiments Faraday concluded, "that the effect is a differential result of the masses of matter present in the magnetic field, and analogous to results presented by liquid and solid dia-magnetic bodies, together with those of a magnetic or paramagnetic character."

Faraday, in Series XXV., next considers the magnetic characters of oxygen, nitrogen, and space—a subject of great interest. As we have just seen, oxygen presents an entirely different character, in relation to magnetism, to that afforded by nitrogen; and Faraday was anxious to arrive at a kind of zero, at which magnetics and dia-magnetics both began to show distinctive action, character, or quality, as in part illustrated by the tables given at pp. 452 and 453, *ante*, in both of which a suppository zero as a vacuum is assigned, dividing the two classes of bodies. Commencing the description of his results, he observes—

"The differential action of two portions of gas, or of any two bodies, may, by a more elaborate method, be examined in a manner far more interesting and important than that just described. The mode of action referred to may even be made the basis of instruments, by which, probably, most important indications and measurements of both magnetic and dia-magnetic actions may be obtained, leading to results which are not even as yet contemplated by the imagination.

"If two portions of matter, gaseous or liquid, are tied together, and placed in a symmetric magnetic field, on opposite sides of the magnetic axis, they will be simultaneously affected. If both are dia-magnetic, or less magnetic than the medium occupying the magnetic field, both will tend to go outward, or equatorially—equally if they are alike, but unequally if they differ. The consequence will be, that if they are placed, in the first instance, equi-distant from the magnetic axis, the supervention of the magnetic force will not alter their position, provided they be alike; but, if they differ, their position will be changed; for the most dia-magnetic will move outward equatorially, pulling the least dia-magnetic inward, until the two are in such new positions that the forces acting on them are equipoised, and they will assume a position of stable equilibrium. Now the distance through which they will move may be used indirectly; or, better still, the force required to restore them to their equidistant position may be employed directly to estimate the tendency each has to go from the magnetic axis; that is, to give their relative dia-magnetic intensities."

Faraday then proceeds to describe the method which he adopted to try these exceedingly interesting experiments, and obtain accurate results. He selected a piece of thin flint-glass tube, and drew it by the blowpipe into long vessels of the shape shown in the following cut. He filled one portion with oxygen, and the other with nitrogen. The two tubes were connected by a thread tied into a loop, and suspended perpendicularly from a torsion balance, so that the middle of each should, when in place, be on a level with the magnetic axis. The arrangement was such, in regard to the electro-magnet (which was furnished with a double core, or keeper, shown in Fig. 260), that the middle part of each tube was level with the middle of the core, and equivalent on each side of it. Under these circumstances, if any motion was given to the balance so as to make its arm vibrate, the vibrations were made with great slowness, in consequence of the weight of the whole moving arrangement, and the small amount of torsion force in the cocoon silk.

Fig. 265.

The moment the magnetic force was thrown into action, all things changed. The oxygen tube was immediately carried inwards towards the axis, and the nitrogen tube driven outwards on the contrary side. The balance swung beyond its new place of rest, and then returned with considerable power, vibrating many times in the period, which before was filled by a single oscillation; and when it had come to its place of rest, or of stable equilibrium, the oxygen tube was about one-eighth of an inch from the iron core, and the nitrogen tube four-eighths distant. Ten revolutions of the torsion axis altered, only in a slight degree, these relative distances.

"The actions which determine the mutual self-adjustment of the oxygen and nitrogen, as regards their place in relation to the magnetic axis, are very simple and evident. In the first place, the glass of the tubes is more dia-magnetic than the surrounding medium, or air, and

therefore each tends to move outwards; but, being equal in nature and condition to each other, they tend to move with equal force when at equal distances, and at those distances compensate each other. If one be driven inwards, it is subjected to a greater exertion of force by coming into a more intense part of the magnetic field; and the other being at the same time outwards, is, for a corresponding reason, in a place of less intense action; and, therefore, as soon as the constraint is removed, the system returns to its position of stable equilibrium, in which the two bodies are equi-distant from the magnetic force.

"The *contents* also of the tubes are subject to the magnetic forces, and, as the result shows, in very different degrees. Either the oxygen tends inwards much more forcibly than the nitrogen, or the nitrogen tends outwards more powerfully than the oxygen; and the difference must exist to a very great degree; for it is such as to carry the glass of the oxygen tube up to a position so near the axis, that it could not by itself, or with mere air inside, retain it for a moment without the aid of considerable restraint. The power with which the tubes only would retain their equi-distant position, combined with the extent to which they are displaced from their position, shows the great amount of force which this conjoint action of the oxygen and the nitrogen leaves free to be exerted in the one direction—namely, from the oxygen inwards, or axially; for though the action be complicated, the result is simple. By former experiments the nitrogen is known to pass equatorially, and the oxygen axially in the air [see *ante*, p. 471]; and the nitrogen tube will pass equatorially according to a certain differential force, depending on the flint glass and the nitrogen on the one hand, and the bulk of air displaced by them on the other. The oxygen tube, in like manner, will tend to pass axially by a differential force, the amount of which will depend upon the tendency of the oxygen to go axially, of its tube to go equatorially, and of their joint relation to the air they displace. But both the tubes and their contents are, by their joint relation to the air and their mechanical connection, so related to each other, that when a force (as of torsion) is employed to restore them to their equi-distant position from the magnetic axis, all consideration of the matter of the tubes, and of the air as a surrounding medium, may be dismissed. The gases within them may be considered as in immediate relation with each other and the magnetic axis, and disembarrassed from all other actions; and the force which may be found needful to place them *equi-distant*, is the measure of their magnetic or dia-magnetic differences."

Faraday then proceeds to consider the effect of rarefaction. He filled tubes of glass with oxygen in such a manner as that one sustained an internal pressure of one atmosphere—that is, equal to that of the atmosphere itself; another was filled so as to have an internal pressure of half an atmosphere; a third, of about ten inches of mercury, or the third of an atmosphere; and a fourth, having been first filled with oxygen, was exhausted to produce within it as complete a vacuum as could be obtained by an excellent air-pump. When the first of these was compared with the other three, the effect was striking: opposed to the half atmosphere, it went towards the axis, driving the expanded portion away; when in relation to the one-third atmosphere, it went inwards, or axially, with still more power; and when opposed to the oxygen vacuum, it took its place as close to the iron core as in the former case, when contrasted with nitrogen. It was manifest that the dia-magnetic power of the glass tube which enclosed it, was the only thing that prevented the oxygen from pressing against the iron core, occupying the centre of the magnetic field.

"This oxygen appears to be a very magnetic substance, for it passes axially, or from weaker to stronger places of force, with considerable power—a conclusion in accordance with the result of former observations. Moreover, it passes more powerfully when dense than when rare; its tendency inwards being apparently in proportion to its density. Hence, as the oxygen is removed, the magnetic force disappears with it, until, when a vacuum is obtained, little or no trace of attraction or inward force remains. No doubt it may be said that dense oxygen is less dia-magnetic than rare oxygen, or a vacuum. This, however, would imply that the acting force of a substance on the oxygen could increase in proportion as the quantity of the substance diminished, which is not, I think, a philosophical assumption; and besides that, other reasons will appear to show that the magnetic condition, which disappears as the oxygen is removed, belongs to, and is dependent upon, that substance, and that oxygen is therefore a truly magnetic body."

Faraday next prepared precisely similar tubes filled with nitrogen. "When these were compared one with another in the magnetic field, they were found to be so nearly alike as not to be distinguishable from each other—*i.e.*, they remained equi-distant from the magnetic axis." He came to the apparently contradictory conclusion, compared to the results of his former researches, that "nitrogen, therefore, appears to be neither magnetic nor dia-magnetic; if it were either, it could not but fall in its specific condition, as it was rarefied; as it is, it is equivalent to a vacuum. If a given space be considered as a vacuum, into which oxygen or nitrogen is to be gradually introduced, as oxygen is added the space becomes more and more magnetic—*i.e.*, more competent to admit of the kind of action distinguished by that word: but the corresponding gradual addition of nitrogen to an empty space, produces no effect of that kind, or the contrary; and the nitrogen is, therefore, neither magnetic nor dia-magnetic, but like space itself."

In reference to any chance of finding the zero point (already frequently referred to), Faraday remarks—"Before determining the place of zero amongst magnetic and dia-magnetic bodies, we have to consider the true character and relation of space free from any material substance.

Though one cannot procure a space perfectly free from matter, we can make a close approximation to it in a carefully-prepared Torricellian vacuum. Perhaps it is hardly necessary to state that both iron and bismuth, in such vacua, are perfectly obedient to the magnet. From such experiments, and also from general observation and knowledge, it seems manifest that the lines of magnetic force can traverse pure space, just as gravitating force does, and as static electrical forces do ; and, therefore, space has a magnetic relation of its own, and one that we shall probably find hereafter to be of the utmost importance in natural phenomena. But the character of space is not of the same kind as that which, in relation to matter, we endeavour to express by the terms magnetic and dia-magnetic. To compare them together would be to confound space with matter, and to trouble all the conceptions by which we endeavour to understand and work out a progressively clearer view of the mode of action, and the laws of natural forces. It would be as if, in gravitation or electric forces, one were to confound the particles acting on each other with the space across which they are acting ; and this would shut the door to advancement. Mere space cannot act as matter does, even though the utmost latitude be allowed to the hypothesis of an ether ; and, admitting that hypothesis, it would be a large additional assumption to suppose that the lines of magnetic force are vibrations carried on by it, whilst, as yet, we have no proof or indication that time is required for their propagation, or in what respect they may, in general character, assimilate to, or differ from, the respective lines of gravitating, luminiferous, or electric forces.

"Neither can space be supposed to have those circular currents round points diffused through it which Ampère's theory assumes to exist around the particles of ordinary magnetic matter, and which I had for a moment supposed might exist in the contrary direction round the particles of dia-magnetic matter. The imagination, restrained by philosophical considerations, fails to find anything in pure space about which the currents could concentrate, or by which they could by any association be attached; and the difficulty, if already immeasurable, would be still greater to those (if there be any) who, assuming that magnetic and dia-magnetic bodies are alike in nature, must assume that there are like currents in both ; for it does not seem possible to add, for instance, phosphorus, having such a magnetic constitution, to space supposed to be of a similar constitution, and yet to have, as a result, a diminution of the magnetic power of the space so occupied.

"As space, therefore, comports itself independently of matter, and after another manner, the different varieties of matter must, in relation to their respective qualities, be considered amongst themselves. Those which produce no effect when added to space, appear to me to be neutral, or to stand at zero. Those which bring with them an effect of one kind will be on the one side of zero, and those which produce an effect of the contrary kind, on the other side of zero : by this division they constitute the two subdivisions of magnetic and dia-magnetic bodies. The law already given expresses accurately these relations ; for in an absolute vacuum, or free space, a magnetic body tends from weaker to stronger places of magnetic action, and a dia-magnetic body, under similar conditions, tends from stronger to weaker places of action."

Faraday then goes on to define the terms magnetic, dia-magnetic, and paramagnetic ; intending the use of the two latter, with the former, to designate the great divisions of all bodies capable of being affected axially or equatorially by magnetism : but these terms and definitions have been already dealt with at p. 462, *ante*.

The paramagnetic force of oxygen and atmospheric magnetism next become the object of Faraday's researches; but in this respect we can only say that his results are of a very speculative character. Assuming that oxygen is a highly magnetic body, he considers that as a great agent in the production of the phenomena of terrestrial magnetism. This assumption, however, whilst modestly made, has yet to be tested by far more extended experimental inquiries. It is impossible, in the limited space to which we are unfortunately confined, to detail all the attempts that Faraday made to arrive at the hoped-for result of truth. His magnetic hypotheses were founded on what we may safety call very large data. He proved that light, associated with matter, is subject to the influence of magnetic force. He also showed that bodies of all kinds, such as the metallic and non-metallic elements—solid, liquid, or gaseous—are equally subjected to magnetic influence, although in opposite characters or affections. We have seen, in the preceding pages, that the most heterogeneous forms of matter are reconcilable to two different conditions—namely, those of paramagnetic and dia-magnetic forces, the distinction of which has been already defined at p. 462, *ante*.

The corollary at which we may arrive, from such researches on the part of Faraday, is by no means difficult to be understood. If all bodies in nature are to be divided into two classes—that is, those which point *axially*, and those which point *equatorially*—we have a most definite stand-point of relationship in regard to matter. We perceive in such a distinction a relation between force and matter, that becomes universal in its character. Our preconceived notions of the divisions that separate iron, nickel, and cobalt from other bodies, are extinguished. If a man, or any other supposed non-magnetic body, can become polar in reference to magnetic force, we must cease to make the distinction that has for ages subsisted in the imagination, of mankind *popular*, and mankind *scientific*. The "landmarks" of universal opinion and generalisation become lost in new facts and theories. We lose our sense of terrestrial personality in the generality of the universe. Our natural feelings confine us to our own globe; but, under the view that the experiments of

Faraday lead us to entertain, we lose that individuality, and become absorbed in the relations of space, force, and matter, that bewilder the mind of the highest philosophers, and lend another illustration, despite of all our advance, of the limited power of human intellect.

For the following condensation of the views of Faraday, in regard to magnetic conducting powers, we are indebted to Mr. Noad.

"The remarkable results respecting oxygen and nitrogen, just described, led Faraday to the idea, that if bodies possess different degrees of conducting power for magnetism, that difference may account for all the phenomena; and its further consideration may assist in developing the nature of magnetic force. By the term *conducting power*, he meant to convey a general expression of the capability which bodies may possess of effecting the transmission of magnetic force, and not to imply anything as to how the process of conduction is carried on; so that if a medium of a certain degree of conducting power occupy the magnetic field, that body will be displaced if another substance, possessed of better conducting-power, be introduced into the field—the result being a differential effect of their difference in conducting power.

"In pure space the lines of magnetic force are straight and parallel; if a paramagnetic body be introduced, the lines are no longer straight, but there will be a concentration of them on the conducting body; so that the space occupied by the conducting body transmits more magnetic force than before. If a dia-magnetic body be introduced, there will be a divergence of the lines, and the space occupied by the dia-magnetic transmits less force than before.

"The two bodies affect, *first*, the direction of the lines of force, not only within the space occupied by themselves, but also in the neighbouring space; *secondly*, the *amount* of force in any particular part of the space within or near them; and the influence of this disturbance is easily made manifest experimentally. A small sphere of iron, exactly equi-distant from the iron poles of an electro-magnet, is in a position of unstable equilibrium, and at such time a great concentration of force takes place through it, and at the iron faces opposite to it, and through the intervening axial spaces. If the iron be a spheroid, its greatest diameter points axially, and the circumstances are more favourable for the concentration of force in the axial line passing through the iron than before. The converse is the case with dia-magnetic bodies, which find their place of stable equilibrium in the spot where the position of paramagnetic bodies is unstable. Their relative and reverse positions in a field of equal magnetic force may be retained in the mind, by conceiving that, if a liquid sphere of a *paramagnetic conductor* were in the place of action, and then the magnetic force developed, it would change in form, and be prolonged axially, becoming an oblong spheroid; whereas, if such a sphere of dia-magnetic matter were placed there, it would be extended in an equatorial direction, and become an oblate *spheroid.*

"The mutual action of two portions of paramagnetic matter in a field of equal magnetic force, is that of repulsion; and it is precisely the same with two portions of dia-magnetic matter. Faraday found, that when lines of power passing across the magnetic field were strengthened by placing in the field a saturated solution of protosulphate of iron, a small movable cylinder of phosphorus, suspended in the middle of the magnetic field, was distinctly repelled by another piece held close to it. Also, when a piece of phosphorus was suspended in water in a field of equal magnetic force, it was repelled equatorially by another piece of phosphorus, but attracted by a tube filled with a saturated solution of protosulphate of iron. Thus, then, *paramagnetic* and *dia-magnetic* bodies attract each other equatorially in a mean medium; but each repels bodies of its own kind."

In connection with the subject of dia-magnetism, Faraday enters into the question of how far the paramagnetic character of oxygen, and the opposite of nitrogen, may effect changes in the direction of the needle. He observes—

"The result of *annual variation* that may be expected from the magnetic constitution and condition of the atmosphere, seems to me to be of the following kind. Assuming that the axis of rotation of the earth is perpendicular to the plane of its orbit round the sun, and dismissing, for the present, other causes of magnetic variation than those due to the atmosphere, the two hemispheres of the earth, and the portions of air covering them, would be affected and warmed alike by the sun; or, at least, would come into a constant relative state, dependent on the arrangement of land and water: and the lines of magnetic force having taken up their position, under the influence of the great dominant causes, whatever they may be, would not be altered by any annual change due to the atmosphere, since the daily mean of the atmospheric effect in a given place, would, at all parts of the year, be alike. Under such circumstances, the intensity and direction of the magnetic forces might be considered constant, presuming no sensible change to take place by the difference in the distance of the sun, which would occur in different parts of the orbit; and, as regards the two magnetic hemispheres, each would be the equivalent or an equal to the other; and they may, for the time, be considered in their mean or normal state.

"But as the axis of the earth's rotation is inclined 23° 28′ to the plane of the ecliptic, the two hemispheres will become alternately warmer and colder than each other, and then a variation in the magnetic condition may arise. The air of the cooler hemisphere will conduct magnetic influence more freely than if in the mean state, and the lines of force passing through it will increase in amount; whilst in the other hemisphere, the warmed air will conduct with less readiness than before, and the intensity will diminish. In addition to this effect of temperature, there ought to be another due to the increase of the ponderable portion of the air in the cooled hemisphere, consequent upon

its contraction, and the coincident expansion of the air in the warmer half, both of which circumstances tend to increase the variation in power of the two hemispheres from the normal state. Then, as the earth rolls on in its annual journey, that which, at one time, was the cooler, becomes the warmer hemisphere, and, consequently, in its turn, sinks as far below the average magnetic intensity as it before stood above it, whilst the other hemisphere changes its magnetic condition from less to more intense.

"As the sum of the magnetic forces that crop out from the earth wherever there is dip on one side of the magnetic equator, must correspond to the sum of like force on the other side, so they would not become more intense in one hemisphere, or more feeble in the other, without a corresponding contraction on the one hand, and enlargement on the other. The line of no dip round the globe may, therefore, be expected to move alternately north and south every year, or some effect equivalent to that take place. The condition of the two hemispheres, under this view, may be conceived by supposing an annual undulation of the force to and fro between them; during which, though neither the character nor the general disposition of the power be altered, there is in one winter a concentration and increase of intensity in the northern parts coincident with a diffused and diminished intensity in the south; and, in summer, the reverse.

"In respect to *direction*, alterations may also be anticipated. In the first place, and assuming that the magnetic poles and the poles of the earth coincide, the dip would increase in the cooling hemisphere towards the middle and polar parts; but it ought to diminish towards the magnetic equator to accord with the concentration of the hemisphere of stronger power and enlargement of the weaker one; whilst, on the other hand, the dip ought to diminish at the polar and middle parts of the warming atmosphere, and increase towards the magnetic equator. The latter would shift a little north and south of its mean place during each year, simultaneously with the whole system of magnetic lines. But as the magnetic poles do not coincide with those of the earth, or with what may be called the poles of the changing temperatures, so a cause of difference in direction may here arise.

"Again, it may be that, as oxygen is cooled, its paramagnetic power may increase in a more rapid proportion than that of the change of temperature, so that the chief alteration of the disposition of the earth's force may be in the extreme northern and southern parts; and, in combination with the holding power of the earth, may even cause a change the reverse of that expected above the lower latitudes. * * * Further, if it be supposed that the whole of a hemisphere *is affected at once* in the same direction by change of temperature, *it will not be affected alike, but differently in different latitudes*, because of the difference in the amount of that change."

The difference of land and water will still further break up any expected uniformity of the general result, and cause that certain parts of the cooling hemisphere shall increase in power more in proportion than other parts; and when these parts lie on opposite sides of the magnetic meridian of any given place, they would probably have the power to cause an alteration in the declination of the needle at that place.

As the annual changes of temperature are less at the equator than in parts more north and south, so there, probably, little or no annual variation could occur; none, indeed, as regards the varying temperature or expansion of the air, but only that portion which is consequent upon the alternate changes of the parts on its opposite sides.

Another effect, which may be considered as an annual variation, but which is connected with the diurnal changes, may be expected. As the daily changes in temperature of the atmosphere, influential upon a given place in north or south medium latitudes, are greater in extent in summer than in winter, so the corresponding magnetic variations may be expected to vary also, being larger in the northern hemisphere when the sun is on the north side of the equator, and less when he is present in the southern hemisphere, and producing like correspondent change there.

From a most important investigation by Colonel Sabine, founded on the results of observations made at Toronto and Hobart Town, the facts appear to be, that the magnetic intensity is greater in both hemispheres in those months which are winter in the northern, and summer in the southern. Similar results are greatly wanted for other localities, and would show whether the different dispersion of land and water has anything to do with the question, or whether the results at Toronto and Hobart Town are true exponents of hemispherical effects. Since Faraday wrote these observations, extended investigations have been made on the subject. At Greenwich, as in many other places in the kingdom, the continent and America, elaborately-devised apparatus have been fitted up, and most satisfactory results, that have been noticed in the article on Magnetism, have been obtained.

The limits of our space prevent us entering more fully into the various opinions expressed by Faraday on the connection of magnetism with our atmosphere; various meteorological phenomena, as the aurora borealis, &c., &c.; the cause of magnetic storms; the general or local effect of temperature in producing variation of the needle; and many other such interesting topics. Generally, however, such questions have been already dealt with in this work; and, as they are of a purely scientific character, their further discussion can with difficulty be rendered in a popular manner.

At a previous page, under the head of Magnetism, we gave some short tables containing the variation of the needle in London, Paris, and Lisbon, observed in recent years. The following tables give the variation for a period, in some cases, of 200 years.

TABLE I.—*Containing the Variation of the Needle, as observed in Denmark, Norway, and Sweden.*

Names of Places.	Year of Obser-vation.	Magnetic Variation.	Names of Places.	Year of Obser-vation.	Magnetic Variation.	Names of Places.	Year of Obser-vation.	Magnetic Variation.
Arendal	1796	20° 21′ w.	Havnefiord	1786	35° 21′ w.	Stadthuk	1768	19° 10′ w.
Arboga	1799	17 25	Holmenshavn	1786	43 9		1790	25 45
Avestad	1799	17 40	Hammerfest	1765	6 50	Stockholm	1718	5 37
Bergen	1768	19 20	Hustappen Island	1766	7 0		1771	13 4
	1791	24 45	Hvalöers Church	1768	16 25		1800	16 20
	1792	25 30	Hveen Island	1672	2 35		1817	15 34
Bommel Island	1792	24 52	Helsingöer	1761	14 0	Salberg	1746	9 0
Bessested	1780	34 30	Hedmora	1748	9 10	Sala	1799	16 0
Christiansund	1768	16 30	Jukasjerwi	1776	11 30	Söderbärke	1746	9 15
Christiansand	1794	22 0	Kielvigs Church	1766	5 30	Sälö Bak	1804	18 30
Christiania	1761	15 15	Karasjok	1768	6 50	Sädankyla	1776	5 30
	1769	16 45	Kongswinger	1779	17 30	Skiervoens Church	1768	16 30
	1816	20 15	Kullens	1803	21 0	Strömstad	1804	18 0
	1817	20 3	Köping	1799	17 15	Sulen Island	1791	27 15
Carlberg	1799	17 5	Nya Kopparberget	1799	17 25	Talvig	1766	6 50
Carlscrona	1716	11 15	Kongsör	1746	9 30	Torneo	1695	7 0
Copenhagen	1649	1 30 E.	Kusamo Church	1776	5 30		1736	5 5
	1672	3 35 w.	Lindesness	1605	7 10 E.		1767	8 50
	1730	10 37	Lofoeden Isles	1608	0 0		1777	11 45
	1770	15 32		1609	0 0	Utsjoki	1748	3 30
	1782	17 41	Lund Pfarrhof	1785	19 30 w.	Upsal	1718	5 37
	1806	18 25	Lyderhorn	1768	19 20		1746	8 45
	1817	18 5	Lindesberg	1746	9 36	Uhma Capel	1762	10 45
	1817	17 55½	North Cape	1769	6 0	Uranienburg	1672	2 35
Drontheim	1761	13 50	Nora	1799	18 35	Wardhus	1748	0 0
	1786	19 0	Norrberke	1799	17 35			0 30
Dyrefiords Haven	1786	42 41	Orebroe	1799	17 7		1775	5 32
Fahlun	1799	18 45	Patrixfiord	1772	33 30	Vadsöe	1816	7 55
Flekkeröe	1783	19 29	Rust Island	1613	4 8 E.	Vangs Church	1793	19 50
Fredericksborg	1810	18 50	Stavanger	1794	22 26 w.	Vesteräs	1799	17 50
Gottenburg	1694	8 30	Skudesness	1613	8 0 E.	Vinga Bäk	1804	19 0
	1748	12 40						

TABLE II.—*Containing the Variation of the Needle, as observed in Great Britain and Ireland.*

Names of Places.	Year of Obser-vation.	Magnetic Variation.	Names of Places.	Year of Obser-vation.	Magnetic Variation.	Names of Places.	Year of Obser-vation.	Magnetic Variation.
Bristol	1666	1° 27′ w.	London	1580	11° 15′ E.	Plymouth	Unknown	13° 24′ E.
	1667	1 33		1657	0 0 w.		1733	13 27 w.
Bushy Heath	1813	24 22 17		1790	23 39	Stromness Harbour	1774	24 0
	1822	24 35 26		1800	24 3·6			
Dublin	1745	18 0 w.		1823	24 9 40			
	1791	27 23						

TABLE III.—*Containing the Variation of the Needle, as observed in Portugal, Spain, and Italy.*

Names of Places.	Year of Obser-vation.	Magnetic Variation.	Names of Places.	Year of Obser-vation.	Magnetic Variation.	Names of Places.	Year of Obser-vation.	Magnetic Variation.
Aranjuez	1798	19° 25′ w.	Cape Finisterre	1768	21° 4′ w.	Madrid	1799	19° 59′ w
Alborne Island	1733	14 12	C. St. Antonio, S.	1792	19 23	Malta	1694	9 15
Braga	1761	16 15	Ferrara	1677	0 0			9 45
Brescia	1676	4 0 E.	Gibraltar Bay	1733	13 38		1708	10 25
Cadiz	1724	5 25 w.		1761	17 11	Minorca, C. Mola	1733	14 34
	1769	17 15		1792	22 6	Padua	1725 / 1730	13 0
	1791	21 56	Lisbon	1638	7 39 E.			
Cape St. Vincent	1733	13 49		1668	0 50 w.		1770	16 20
Cape St. Gatt, Sp.	1733	13 56		1697	4 18	Rome	1670	2 15
Cape St. Mary's, P.	1734	14 20		1782	19 51		1730	11 0
Cape Finisterre	1589	7 40 E.	Loretto	1756	15 35		1788	17 12

TABLE IV.—*Containing the Variation of the Needle in Russia.*

Names of Places.	Year of Observation.	Magnetic Variation.
Awatscha Bay......	1805	5° 39′ E.
Barrannoi Kamen	1787	17 40
Barnaul	1770	2 45
Casan	1761	2 25 W.
	1805	2 2 E.
Catharinenburg	1761	0 50
	1805	5 27
Carchow	1783	7 27 W.
	1811	5 17
Cherson	1782	10 10
Caffa	1772	7 0
Dmitrewsk	1771	5 49
	1773	6 30
Druia	1773	10 40
St. Elizabeth	1770	9 45
Gluchow	1770	5 30
Gurief	1769	3 35
Gloubouca	1615	18 0
Irkutsk	1735	11 5
	1805	0 32 E.
Jakutskoi	1768	5 15 W.
	1769	5 0
	1788	2 0
Jarowslawl	1782	4 0
Jenicola	1785	7 15
Kola	1769	1 45
Krementschuk ...	1770	8 0

Names of Places.	Year of Observation.	Magnetic Variation.
Krasnojarsk	1735	2° 0′ W.
Kiachta	1735	3 0
	1735	2 45
Kiow	1773	9 15
Kaluga...............	1784	7 45
Kursk	1784	5 0
Kostroma	1782	3 45
Kesloff, or Kozlov	1785	11 38
Lubny	1782	9 5
Moscow	1732	5 26
Mosdok	1785	6 40
Nezshni Kovima...	1787	14 40 E.
Nizni-Udinsk ...	1735	3 15 W.
	1805	2 40 E.
Nertchinsk	1735	3 0 W.
Neschin	1779	10 0
	1782	10 0
Orenburg	1769	3 30
		3 20
Orsk	1769	0 15
Orel	1781	9 0
Petersburg	1726	3 15
	1782	7 30
	1812	7 16
Perm	1805	1 10 E.
Petropaulowska	1779	6 19
	1805	5 20

Names of Places.	Year of Observation.	Magnetic Variation.
Petrosawodsk	1785	5° 9′ W.
Ponoi	1769	1 10 E.
Peczora	1611	22 30 W.
Pustozerskoi	1614	20 0
Revel	1751	7 30
Riga..................	1750	8 0
Samara	1770	8 10
Sietscha	1770	9 15
Sisran	1770	5 50
Selenginsk	1735	0 30
Saratow	1773	3 28
Sewastropol.........	1785	11 13
Tscherkask	1770	5 50
Tara..................	1805	6 6 E.
Tomsk	1805	5 37
Tobolsk	1716	0 0
	1761	3 46
	1805	7 9
Tambow	1784	5 45 W.
Umba	1769	3 30
Ufa	1769	1 30 E.
Ustkamenogorskoi	1770	2 0
Wologda	1785	3 52 W.
Woronetz	1783	8 0
Zarizin...............	1770	4 50

TABLE V.—*Containing the Variation of the Needle in Holland, Prussia, the Netherlands, and Switzerland.*

Names of Places.	Year of Observation.	Magnetic Variation.
Antwerp	1600	9° 0′ E.
Amsterdam	1767	17 30 W.
Augsburg	1772	16 40
	1798	18 26
Berlin	1717	10 42
	1780	16 48
	1805	18 2
Bonne	1782	17 20
	1788	18 55
Dantzig	1628	1 0
	1760	11 0
	1811	13 48
Dusseldorf	1783	20 0
Dresden	1797	18 30
Freyberg	1769	15 40
Frankfort - on - Maine	1774	16 32
Franeker	1771	19 30

Names of Places.	Year of Observation.	Magnetic Variation.
Franeker	1773	18° 30′ W.
Geneva............	1797	19 40
	1804	21 13
Grätz	1770	15 50
Göttingen	1777	16 48
Hague	1782	20 16
Inspruck	1787	22 40?
Konigsberg	1600	0 0
	1628	1 0
	1642	1 5
	1774	13 30
Leipsic...............	1749	13 0
Manheim.........	1776	19 48
	1785	19 44
	1786	19 53
	1787	20 2
	1788	20 5
Mittau...............	1783	10 52

Names of Places.	Year of Observation.	Magnetic Variation.
Middleburg......	1786	21° 14′ W.
	1788	21 56
Nuremburg	1685	5 5
Prague............	1774	15 45
	1787	17 20
Rotterdam	1767	19 0
Regensburg......	1784	17 49
	1786	19 11
Tübingen.........	1747	13 34
	1752	14 37
Tankermund	1814	19 0
Vienna............	1638	0 0
	1760	13 0
Wurtzburg	1781	18 40
	1787	18 35
Zurich...............	1762	15 15

TABLE VI.—*Containing the Variation of the Needle, as observed in Turkey in Europe.*

Names of Places.	Year of Observation.	Magnetic Variation.
Akiermann	1771	9° 25′ W.
Bender................	1772	9 45
Bucharest	1772	11 36

Names of Places.	Year of Observation.	Magnetic Variation.
Constantinople .	1600	0° 0′ W.
	1625	2 0
	1694	9 0

Names of Places.	Year of Observation.	Magnetic Variation.
Constantinople ...	1694	12° 0′ W.
Ofen...............	1781	16 45
	1788	16 36

TABLE VII.—*Containing the Variation of the Needle, as observed in Asia and the adjacent Islands.*

Names of Places.	Year of Obser-vation.	Magnetic Variation.	Names of Places.	Year of Obser-vation.	Magnetic Variation.	Names of Places.	Year of Obser-vation.	Magnetic Variation.
Aden, Arabia ...	1612	13° 40' w.	Dabul, India ...	1610	15° 34' w.	Mazeira Island, Arabia	1613	20° 10' w.
	1612	12 40		1611	16 30			
	1674	15 0	Daman, India......	1612	16 30	Mindanao—		
	1723	13 50	Darsina, Arabia ...	1612	15 2	Cape St. Augustin	1767	1 45 E.
	1723	13 42	Derbent, Persia ...	1712	12 0			
Aleppo, Syria......	1781	12 30	Doy, or Doa, Molucca Isl. .	1613	5 20 E.	Mocha, Arabia	1723	13 24 w.
Alexandretta, Syria	1694	14 22					1769	12 33
Alguarda, near Goa	1722	5 49	Firando, an isl. near Japan ...	1613	2 50		1776	11 20
Anjanga, India ...	1724	4 17				Nankin, China ...	1685	0 0
Ava, India	1689	5 0	Goa, India	1609	16 0 w.	Nicobar, India ...	1685	7 5
Bab-el-Mandeb	1723	14 20		1724	5 41	Paliacate, India	1611	13 15
	1723	14 8	Guadal Cape, Persia	1613	17 15		1613	13 10
Bachian Island, Amasane Bay	1612	4 48 E.		1616	18 0	Patapilli, India	1611	12 47
			Hainan Isl., China	1613	0 50		1611	12 22
Baixos de Chagos Island	1610	19 50 w.	Hyderabad, 27th June	1804	1 16·39 E.		1613	13 50
						Paul's Island, St.	1677	23 30
Balasore, India ...	1680	8 20	Ingana Island......	1607	4 13 w.	Pekin	1755	2 0
Do. Cape Palmiras	1722	3 33	Iriseh	1797	8 14	Pondicherry	1689	7 0
Banca Island	1791	0 0	Ispahan, Persia ...	1787	7 30	Prince's Island, near Java ...	1767	1 0
Beit-el-Fakih	1762	11 50	Jask Cape, Persia	1616	19 20		1780	0 54
Bombay, India...	1676	12 0				Pulo Condore Island	1620	1 0
	1751	5 12	Java Bantam ...	1609	3 0		1780	0 14
	1721	5 16	Batavia .	1767	1 25	Rasalgat, Cape, Arabia	1613	19 20
	1722	5 7		1768	0 25			
	1723	5 10	Palimbang .	1605	3 20	Rogipore (Raja-poor)	1722	4 58
Calicut............	1722	4 5	Judda, Arabia...	1769	11 52			
	1772	4 9		1776	12 55	Roquepiz Island...	1610	23 30
Canton............	1690	2 25	Kasbin, Persia ...	1787	7 33	Sinde	1613	16 45
	1722	1 30	Kerguelen's Land	1776	27 44	Singanfu, China ...	1689	3 17
Cape Comorin, India	1601	16 0	Louveau, Siam	1685	4 45	Sinope..............	1797	10 18
	1620	14 20		1685	0 30 ?	Sually	1610	16 40
	1680	8 45		1686	4 45		1611	16 30
	1688	7 30		1688	4 30		1612	17 0
	1723	2 51	Lucepara Island ...	1767	0 0	Sumatra—		
Carwar Bay, India	1722	5 40	Macao	1616	1 30	Achen	1610	6 15
	1722	5 4		1779	0 32	Marlborough Ft.	1794	1 10 E.
	1723	5 8	Machian Island, near Gilolo ...	1612	4 12 E.		1795	1 8
	1724	5 32		1613	3 38	Priaman	1612	4 10 w.
Celebes, Bonthain.	1767	1 16	Madras, India...	1722	2 52 w.		1613	4 50
Ceylon—				1723	3 16	Sunda Strait	1615	3 30
Friar's Hood	1722	2 12	Madura Island, near Java ...	1768	0 30	Surat	1611	16 23
	1722	2 21					1723	5 22
Point de Galle	1613	13 24	Maldevische Canal	1605	17 0	Tecu Island.........	1612	4 40 E.
	1723	2 46		1722	4 16	Tellichery, India	1722	4 21 w.
	1723	2 45	Mangalore, India	1722	5 24		1722	4 4
Chandernagore, India	1731	3 0		1722	5 25	Tijis.................	1613	18 30
	1750	0 0		1723	5 5	Ula, China	1682	1 40 E.
Chaul, India	1721	5 27	Masulipatam, India	1610	12 22	Xin-Yam, China	1682	0 0 w.
Cochin, India...	1614	15 0						
	1724	4 16						

TABLE VIII.—*Containing the Variation of the Needle, as observed in France.*

Names of Places.	Year of Obser-vation.	Magnetic Variation.	Names of Places.	Year of Obser-vation.	Magnetic Variation.	Names of Places.	Year of Obser-vation.	Magnetic Variation.
Antibes	1682	3° 40' w.	Havre de Grace	1767	19° 15' w.	Paris	1700	7° 40' w.
Bayonne	1680	1 20		1782	22 15		1750	17 15
Boulogne............	1767	17 26	Malo, St............	1681	2 0		1780	20 35
Brest	1679	1 45	Marseilles	1761	18 0		1800	22 12
	1771	20 10		1798	20 55		1819	22 29
	1798	25 30	Montpelier	1644	1 10	Royan	1680	1 20
Calais	1681	4 30	Paris	1541	7 0 E.	Toulon..............	1682	2 45
	1767	19 30		1580	11 30	Toulouse	1747	15 10
Dieppe...............	1619	6 30 E.		1660	1 0		1756	15 45
Dunkirk	1767	18 33 w.		1667	0 15 w.	Ushant Island......	1776	23 1

TABLE IX.—*Containing the Variation of the Needle, as observed in America and the adjacent Islands.*

Names of Places.	Year of Observation.	Magnetic Variation.
Acapulco	1744	3° 0′ E.
Albany Fort	1730	23 0 W.
Antigua Island	1774	17 0
	1727	4 28 E.
	1761	4 31 W.
Augustin, Cape	1670	5 30 E.
Bahia, Brazil	1708	4 30
Barbadoes, Carlisle Bay	1726	4 24
	1761	3 47
Bastimento's Isle	1726	7 48
Bear Island	1596	13 0
	1610	13 30
Beverley	1781	7 4 W.
Boston	1708	9 0
	1741	7 30
Buenos Ayres	1708	15 32 E.
Button Isle	1615	24 0 W.
	1730	39 0
Cambridge	1708	9 0
	1783	6 52
Cape Cathivas	1726	7 24 E.
Cape Christian, Greenland	1605	12 15 W.
Cape Corientes	1684	4 28 E.
Carthagena	1705	7 12
	1726	6 50
Catherine's Island, St.	1712	12 0
	1785	12 0
	1804	7 51
Cayenne Island	1672	11 0
	1682	5 30
Chesapeake Bay	1732	4 58 W.
Christopher's, St., Basseterre	1726	4 10 E.
Cod Bay	1789	6 45 W.
Conception	1709	10 20 E.
Coquimbo	1700	8 32
Croix Island, St.	1783	3 20
Cuba—		
Pau de Matanzas	1726	4 24
Havannah	1732	4 30
Cumana	1799	4 14
Curaçoa	1704	6 40
Deseado Island	1726	3 27
Desolation Sound	1792	19 16

Names of Places.	Year of Observation.	Magnetic Variation.
Diego, St., California	1792	11° 0′ E.
Discovery Harbour	1792	21 30
Domingo—		
Cape François	1772	5 20
	1776	5 30
	1783	5 32
Alta Vela Island	1728	6 2
Fernando Naronha	1610	8 10
Florida, Cape	1726	3 26
Frio, Cape	1670	12 10
Fuego, Terra del—		
Christmas Sound	1774	24 43
Good Success Bay	1769	24 9
Godthaab, Greenland	1784	50 30 W.
	1787	51 21
Guadaloupe	1726	3 22 E.
Hermit Island	1707	20 0
Jamaica—		
Portland Point	1726	6 2
Port Royal	1726	4 31
Black River	1732	6 2
Jamba Point	1726	6 20
Juan Fernandez	1767	11 0
Lima	1709	6 15
Marie Galante Island	1726	3 40
Martha Cape, St.	1704	7 6
Martinique	1682	4 10
	1704	6 10
	1760	5 41
Massafuera Island	1765	9 36
	1767	10 24
	1795	9 15
Mendocino, Cape	1693	2 0
	1786	12 24
Mexico	1769	5 30
Monterrey	1795	12 22
Montserrat	1765	5 32
Moose Fort, Hudson's Bay	1774	17 0 W.
Musquito Cove, Greenland	1776	50 36

Names of Places.	Year of Observation.	Magnetic Variation.
Newfoundland—		
Fort St. Pierre	1772	19° 15′ W.
Nootka	1778	19 45
	1792	18 22 E.
Norriton	1770	3 8 W.
Norton Sound	1778	25 45 E.
Paraibo	1698	5 35
Pisco	1707	7 0
Porto Bello	1704	7 25
Quebec	1649	16 0 W.
	1686	15 30
Quito	1742	8 30
Resolution Island	1615	24 6 W.
Rio Janeiro	1768	7 34 E.
	1787	6 12
Santiago, Chili	1794	14 28
Savage Island	1615	27 30
Sebalt Island	1683	23 10
	1707	23 0
Smith's Sound	1616	57 0 W.
Spitzbergen—		
Bell Sound	1613	13 11
Cross Rheid	1596	16 0
Horn Sound	1610	16 0
	1613	12 37
Magdalen Sound	1614	25 0
Poopy Bay	1613	15 21
Read Beach	1596	16 0
Vogelsang	1773	20 38
Unalashka Samganoodha Harbour	1778	19 59 E.
Valdivia	1670	8 60
Valparaiso	1709	9 30
	1795	14 49
Vera Cruz	1769	6 40
	1776	7 30
Wales', Prince of, Fort	1725	21 0 W
	1742	17 0
	1769	9 41
Ylo, Peru	1710	6 38 E.
York, New	1686	8 45
	1723	7 20
	1789	4 20

TABLE X.—*Containing the Variation of the Needle, as observed in Africa and the adjacent Islands.*

Names of Places.	Year of Observation.	Magnetic Variation.
Ab-dal-Curia Island, west of Sowtora	1612	17° 23′ W.
	1723	12 43
Accara Fort, Guinea	1726	11 25
	1726	11 53
Alexandria, Egypt	1638	5 45
	1798	13 6
Algiers	1731	14 0
Angoxa	1611	12 1
Ascension Isl.	1678	1 0 E.
	1754	8 6 W.
	1775	10 52

Names of Places.	Year of Observation.	Magnetic Variation.
Ascension Isl.	1806	15° 40′ W.
Azore Islands—		
Fayal Bay	1589	3 5 E.
	1775	22 7 W.
Flores	1600	0 0
Marie	1610	1 40 E.
Bab-el-Mandeb	1723	14 20 W.
	1723	14 8
Baxoz de Chagos	1610	19 50
Boobam	1616	13 12
Bourbon, Isle of—		
Mascarenhas	1614	22 48

Names of Places.	Year of Observation.	Magnetic Variation.
St. Paul's Bay	1722	19° 49′ W.
	1722	19 44
Canary Islands—		
Ferro	1724	5 0
	1769	17 30
	1802	19 55
Lanzarote	1610	6 6 E.
Madeira, Funchal	1727	6 58 W.
	1766	14 10
	1766	16 0
	1771	18 0
	1783	18 22

TABLE X.—*Continued.*

Names of Places.	Year of Observation.	Magnetic Variation.
Canary Islands—		
Madeira, Funchal	1802	20° 21′ w.
Grand Canary...	1610	6 6 E.
Teneriffe, Santa Cruz	1769	15 43 w.
	1770	15 30
	1776	14 41
	1776	15 55
	1785	15 52
	1788	20 1
	1792	16 32
	1803	16 1
Cape Coast	1726	11 55
	1726	12 10
	1726	11 46
Cape Verd Islands.		
Porto Praya, St. Jago ...	1725	4 5
	1766	8 20
	1772	10 45
	1791	14 12
Mayo	1725	3 32
	1776	9 32
Sal	1610	3 30 E.
Cairo	1694	12 15 w.
	1761	12 25
	1762	11 40
	1798	12 0
Comora Islands—		
Angoxa, on coast of Africa	1611	13 0
	1721	19 12
	1721	19 44
	1721	20 33
Anjouan	1722	20 39
	1722	20 33
Mayotta	1722	21 12
	1722	20 24

Names of Places.	Year of Observation.	Magnetic Variation.
Comora Islands—		
Molalio	1611	15° 20′ w.
Damietta, Egypt...	1694	12 30
Doara, Ajan......	1611	17 36
	1611	17 20
Edward's Island, Prince	1776	26 15
France, Isle of, (Mauritius)...	1609	21 0
	1722	18 46
	...	18 39
	...	19 7
	...	19 45
Good Hope, Cape of—		
Cape L'Aguillas	1609	0 12
Saldanha Bay	1605	0 30 E.
	1614	1 30 w.
Simon's Bay	1780	22 16
	1791	23 40
Table Bay ...	1614	1 45
	1667	7 15
	1675	8 28
	1687	8 30
	1699	11 0
	1702	12 50
	1706	13 40
	1708	14 0
	1721	16 25
	1724	16 27
	1724	16 18
Goree	1682	0 0
	1769	12 15
	1772	10 30
Guardafui, Cape	1610	17 35
	1723	12 34

Names of Places.	Year of Observation.	Magnetic Variation.
Helena, St., Island of.........	1600	8° 0′ E.
	1691	1 0 w.
	1806	17 18
Hermanas Isl., near Cape Guardafui ...	1612	17 23
Madagascar—		
Augustin's Bay	1607	15 30
	1721	23 48
Antongill Bay	1661	22 30
	1761	18 0
Fort Dauphin	1661	19 0
	1761	22 7½
Foul Point	1762	16 45
St. Sebastian, Cape.........	1600	16 0
	1722	18 36
Nosf-Gombi, an island near Madagascar...	1722	20 0
Salee Roads	1735	12 19
Sierra Leone ...	1608	1 50 E.
	1725	5 12 w
Socotra, Island of...............	1611	16 0
	1776	8 6
St. Mary's Isl., near Madagascar	1610	19 50
	1722	19 53
St. Thomas, Isle of...............	1726	14 48
	1726	14 32
Sunken Rocks, S. lat. 31° 48′	1606	21 0
Trinidad Island, S. lat. 20° 45′; W. long. 29° 30′	1615	12 0 E.
Tripoli...............	1733	13 22 w.

From these tables it will be seen that the variation astonishingly differs in regard to time and place. Faraday made many speculations as to the cause of these differences, and that of variation generally, calling into his aid the discoveries that he had made in electro-magnetism and dia-magnetism. It is evident, from what has been already advanced on those subjects, that magnetism may be considered as an affection of all bodies, which Faraday divides into two classes only—namely, the *paramagnetic*, including those popularly called magnetic, such as iron, nickel, and cobalt; and *dia-magnetic* bodies, on which extended remarks have been already made in this article.

It yet remains, however, for us satisfactorily to account for the cause of terrestrial and universal magnetism. Not only are solid, liquid, and gaseous bodies the subjects of magnetic action; but, as we have seen in Faraday's wonderful experiment, a ray of polarised light may be magnetised. And, still more recently, polarised heat has been similarly affected. Here, then, we can trace, to a large extent, the universality of one force causing various developments. Motion is evidently that which in all cases produces force. Faraday, in his speculations on the relation of gravity to electricity, magnetism, light, and heat, threw out the hint that all these powers or forces, and chemical action, might eventually be considered as arising from one cause; hence the modern idea of the correlation of forces that has been the subject of deep investigation by Tyndall, Grove, and other eminent philosophers. By the term correlation of force, we mean that intimate connection, relationship, or even possible conversion of one into the other. As we have already seen, heat can produce electricity and light, whilst it greatly influences the intensity of magnetism under all circumstances. Light has possibly a magnetic effect, as indicated by the experiments of Morichini, Somerville, and others. Electricity, we have abundantly shown, can produce heat, light, and electricity. Magnetism we have also seen to be productive of heat, light, and electricity; and, indirectly, reproductive of itself, as in Wilde's magneto arrangement. In a preceding page we have detailed Faraday's speculations in respect to the relations of gravity and magnetism. We have also seen, by the experiments of Arago, Herschel, and others, that the rotation of non-magnetic metals greatly affects the magnetic needle, causing its disturbance from a still position, or bringing it into the latter from an oscillating one; whilst, on the other hand, it has

been shown that a copper disc rotating rapidly between the poles of an electro-magnet, is immediately brought to rest when the voltaic current is caused to magnetise the iron poles of the electro-magnet.

Again, daily observations show that the magnetic needle is directly affected by the solar influence—most possibly, as Faraday first suggested, by increase or decrease of temperature. His speculations on the cause of this diurnal variation were epitomised in the page immediately preceding the foregoing tables.

So much, for the present, in respect to what are generally and conventionally termed undulatory forces. If we turn to others, this correlation of force will still be evident. Take, for example, the force of chemical attraction. If we add strong sulphuric acid to cold water, the mixture rises to a temperature exceeding that of boiling water, showing the evolution of latent heat; whilst, on the other hand, by dissolving certain salts in water, an opposite or freezing effect can be produced. Again, by chemical action, as in the voltaic battery, we generate simultaneously light, heat, electricity, and magnetism. Still further, as the reciprocal of these effects, heat, light, electricity, and magnetism are each and all capable of producing chemical action, as we have abundantly shown in the preceding pages.

Next, we may notice how modification of cohesive force may cause the evolution of other forces. If we hammer a piece of iron, or submit it to much friction, heat and light are abundantly obtained, accompanied with a change of the cohesive properties of the material operated on. If a piece of loaf sugar be pounded in a mortar, coffee be ground in a mill, and under many other similar circumstances, electricity is developed to a considerable extent. By friction of glass, resin, and other substances, we obtain usually all the phenomena of static or frictional electricity. Similarly, by the disturbance of the molecules of a body, as in hammering a poker, in the direction of the dip and the magnetic meridian, magnetic polarity, &c., are developed.

From these results we gather two facts—the first being that force depends on motion; and that, secondly, force once generated by motion becomes indestructible. At times, the presence of both force and motion may be so disguised as to make them insensible to all our powers of observation. It has already been shown how delicate must be some of our instruments to detect the least sign of the presence of electric and magnetic disturbance. But a still more popular illustration of this point is found in the fact that, until recently, we were utterly unaware that the earth is in a constant state of tremor—equivalent, indeed, although not in degree, to the earthquakes of some countries, and yet constantly in operation in our own, where an earthquake would be considered as one of the most extraordinary of natural phenomena. Motion is necessarily a sign of the action of force on matter. This, once put into motion, propagates the vibrations of the force acting on it *ad infinitum*; this occurs in the varied forms of calorific, luminous, electric, magnetic, or chemical action, according to the circumstances of the origin of the force, or those under and on which it acts.

On this interesting question, Mr. W. R. Grove, in his *Correlation of Physical Forces*, remarks—"Can we suggest a proposition, definitely conceivable by the mind, of force without antecedent force? I cannot, without calling for the interposition of creative power, any more than I can conceive the sudden appearance of a mass of matter come from nowhere, and formed from nothing. The impossibility, humanly speaking, of creating or annihilating matter has long been admitted; though, perhaps, its distinct reception in philosophy may be set down to the overthrow of Phlogiston, and the reformation of chemistry at the time of Lavoisier. The reason for the admission of a similar doctrine as to force, appears to be equally strong with regard to matter. There are many cases in which we never, practically, prove its cessation of existence, yet we do not the less believe it. * * * The evidence we acquire of the continued existence of matter is by the continued exertion of the force it exercises, as, when we weigh it, our evidence is the force of attraction; so, again, our evidence of force is the matter it acts upon. Thus matter and force are correlates, in the strictest sense of the word; the conception of the existence of the one involves the conception of the existence of the other: the quantity of matter, again, and the degree of force, involve conceptions of space and time."

The interesting nature of this subject would lead us, as a matter of choice, much more largely to dwell upon it; but the limits of our space forbid us so doing. Yet it must also be remembered that, at present, we have but a glimpse only of the connection or correlation that subsists between the forces of nature. We are just as much in the dark respecting the subject as the scientific world was in respect to gravitation in the days preceding Sir Isaac Newton. As Mr. Grove justly remarks, however, "every one has a right to view these facts through any medium he thinks fit to employ; but some theory must exist in the minds of those who reflect upon the many new phenomena which have recently, and more particularly during the present century, been discovered. It is by a generalised or connected view of past acquisitions in natural knowledge that deductions can best be drawn as to the probable character of the results to be anticipated. It is a great assistance, in such investigations, to be intimately convinced that no physical phenomenon can stand alone; each is inevitably connected with anterior changes, and as inevitably productive of consequential changes, each with the other, and all with time and space; and, either in tracing back their antecedents, or following up their consequents, many new phenomena will be discovered, and many phenomena, hitherto believed distinct, will be connected and explained: explanation is, indeed, only a relation to something more familiar, not more known—*i.e.*, known as to causative or creative energies.

CHAPTER XV.

ANIMAL ELECTRICITY.

THERE can be scarcely a doubt that electricity has, more or less, to do with the life of animals. We have not the least belief in what is called electro-biology, mesmerism, nor any of the *et hoc omne genus.* All that may be safely termed the popular forms of such subjects are simply beneath the notice of *common sense*, let alone *science*, conventionally so called; and therefore require no remark here.

It cannot, nevertheless, be doubted that a great analogy, not to say an identity, subsists between many of the functions of animals and electrical agency. Electricity, in a variety of forms, has for a long period been a therapeutic agent. Properly applied, it simultaneously and necessarily affects the nervous and muscular systems. It *seems*, in fact, to highly imaginative minds, to take the place of vital energy—or perhaps, more properly, the cause of that energy; for there are many who prefer to believe that the *pneuma*, or *soul* of man, had not, in the strict sense, a divine origin. Indeed, as of old, the fool hath said, There is no GOD.

But this work cannot be in any way devoted to polemical discussion, however much, for the moment, we may have diverged from a rule in its arrangement and objects. Our purpose is simply to place *facts* before the judgment of our readers. We have no business with any theory unsupported by well or well-assumed facts. Our guides are Bacon and Faraday—each having taught, in the most emphatic of human language, that experiment alone is the source of truth.

If we were to enter into an analysis of the organs and functions of sensation, we should be led into a long, tedious, and, perhaps, impossible discussion. An appeal, however, to the organs and functions, in regard to their action, and relating to all of our readers, places the present question essentially in a popular point of view. Neuralgia, rheumatics, and other allied affections, appeal to the common experience of humanity. There is no mistaking the force of that appeal, simply because, as we have just stated, the experience is too universal. The question thence arises—"What relation has electricity to such affections, whether as a cause or cure?"

Every one, almost, knows that on making contact with the terminals of a voltaic battery, a Leyden jar, a coil machine, or any other arrangement by which an intense current of electricity is generated, a powerful shock to the nervous and muscular systems results, followed, according to the strength of the shock, by muscular contractions of the wrist, elbows, or chest, dependent on the force or power of the shock. Even the simple application of a half-crown on one side of the tongue, and of a piece of zinc on the other—both being in contact at one edge—is sufficient to excite and act on the muscular and nervous system of the head, and to produce, to a very limited extent, an electric shock. If a piece of tinfoil be placed beneath the eyelid, and a piece of silver in the mouth, and the two be brought into contact, an effect resembling a flash of light will be perceived on the eyeball, resulting from an excitation of the optic nerve, similar to that produced from a blow on the eye. It matters not whether the eyes are open or closed, the effect is precisely the same; and it shows that the exciting cause is simply electricity in such a case. "If the pupil of the eye is watched by another person when this effect is produced, it will be seen to contract at the moment the metals are brought into contact."

"If the hind legs of a frog are placed upon a glass plate, and the crural [or leg] nerve, dissected out of one, be made to communicate with the other, it will be found, on making occasional contacts with the remaining crural nerve, that the limbs of the [newly killed] animal will be agitated at each contact. Aldini produced very powerful muscular contraction by bringing part of a warm-blooded and a cold-blooded animal into contact with each other; as, for example, the nerve and muscle of a frog with the sanguineous flesh of the neck of a newly-decapitated ox; also, by bringing the nerve of one animal into contact with the muscle of another."

Perhaps the most astonishing effects of galvanic agency on the nervous and muscular systems, are detailed in the following account of experiments conducted by the late Dr. Ure, on the body of a criminal, executed by hanging, at Edinburgh. They were first published in the *Journal of Science and Arts* (Edinburgh); but afterwards detailed in Dr. Ure's *Dictionary of Chemistry*, under the head of Galvanism.

"The subject of these experiments was a middle-sized, athletic, and extremely muscular man, about thirty years of age. He was suspended from the gallows nearly an hour, and made no convulsive struggle after he dropped; while a thief, who was executed along with him, was violently agitated for a long time. He was brought into the anatomical theatre of our University about ten minutes after he was cut down. His face had a perfectly natural aspect, being neither livid nor tumefied, and there was no dislocation of the neck.

"Dr. Jeffray, the distinguished professor of anatomy, having, on the preceding day, requested me to perform the galvanic experiments, I sent to his theatre the next morning, with this view, my minor voltaic battery, consisting of 270 pairs of 4-inch plates, with wires of communication, and pointed metallic rods with insulating handles, for the more commodious application of the electric power. About five minutes before the police officers arrived with the body, the battery was charged with dilute nitro-sulphuric acid, which speedily brought it into a state of intense action. The dissections were skilfully executed by Mr. Marshall, under the superintendence of the professor.

"*Experiment* 1.—A large incision was made in the nape of the neck, just below the occiput; the posterior half of the atlas vertebra was then removed by bone forceps; when the spinal marrow was brought into view, a profuse flow of fluid blood gushed from the wound, inundating the floor. A considerable incision was at the same time made in the left hip, through the great gluteal muscle, so as to bring the sciatic nerve into sight; and a small cut was made in the heel: from neither of these did any blood flow. The pointed rod connected with one end of the battery, was now placed in contact with the spinal marrow, while the other rod was applied to the sciatic nerve; every muscle of the body was immediately agitated with convulsive movements, resembling a violent shuddering from cold. The left side was most powerfully convulsed. On moving the second rod from the hip to the heel, the knee being previously bent, the leg was thrown out with such violence as nearly to overturn one of the assistants, who in vain attempted to prevent its extension.

"*Experiment* 2.—The left phrenic nerve was now laid bare at the outer edge of the *sterno-thyroideus* muscle, from three to four inches above the clavicle; the cutaneous incision having been made by the side of the sterno-cleido-mastoideus. Since this nerve is distributed to the diaphragm, and since it communicates with the heart through the eighth pair, it was expected, by transmitting the galvanic current along it, that the respiratory process would be renewed. Accordingly, a small incision having been made under the cartilage of the seventh rib, the point of the one insulating rod was brought into contact with the great head of the diaphragm, while the other point was applied to the phrenic nerve in the neck. This muscle, the main agent of respiration, was immediately contracted, but with less force than was expected. Satisfied, from ample experience on the living body, that more powerful effects can be produced by galvanic excitation, by leaving the extreme communicating-rod in close contact with the parts to be operated on, while the electric chain or circuit is completed by running the end of the wires along the top of the plates in the last trough of either pole, the other wire being steadily immersed in the last cell of the opposite pole, I had immediate recourse to this method. The success of it was truly wonderful—full, nay, laborious breathing instantly commenced; the chest heaved and fell; the belly protruded, and again collapsed with the relaxing and retiring diaphragm. This process was continued, without interruption, as long as I continued the electric discharges. In the judgment of many scientific friends who witnessed the scene, this respiratory experiment was, perhaps, the most striking ever made with philosophical apparatus.

"Let it also be remembered, that for full half-an-hour before this period, the body had been well-nigh drained of its blood, and the spinal marrow severely lacerated. No pulsation could be perceived meanwhile at the heart or wrist; but it may be supposed that but for the evacuation of blood, the essential stimulus of that organ, this phenomenon might also have occurred.

"*Experiment* 3.—The super-orbital nerve was laid bare in the forehead, as it issues through the supra-ciliary foramen in the eyebrow; the one conducting-rod being applied to it, and the other to the heels, most extraordinary grimaces were exhibited every time the electric discharges were made, by running the wire in my hand over the edges of the plates in the last trough, from the 220th to the 270th pair: thus fifty shocks, each greater than the preceding ones, were given in two seconds. Every muscle of his countenance was simultaneously thrown into fearful action; rage, horror, despair, and anguish, and ghastly smiles united their hideous expression in the murderer's face, surpassing far the wildest representations of a Fuseli or a Kean. At this period several of the spectators were obliged to leave the room from terror or sickness; and one gentleman fainted.

"*Experiment* 4.—The last galvanic experiment consisted in transmitting the electric power from the spinal marrow to the ulnar nerve, as it passes by the internal condyle at the elbow; the fingers now moved nimbly, like those of a violin performer; an assistant, who tried to close the fist, found the hand to open forcibly in spite of his efforts. When one rod was applied to a slight incision on the top of the fore-finger, the fist being previously clenched, the fingers extended instantly; and from the convulsive agitation of the arm, he seemed to point to the different spectators, some of whom thought he had come to life. About an hour was spent in these operations."

This interesting, although horrible, experiment has been once or twice repeated, under somewhat similar circumstances, and nearly with the same results; that is, making allowance for exaggeration in description, the effects have been nearly allied to those just described. It has been stated that a man, executed by hanging, was actually restored to life; but, according to the same account, the resuscitated individual immediately afterwards died of apoplexy. We lay, however, no stress whatever on such statements, not because they have been made a kind of foundation for the belief that electricity is a source of animation, but simply because we consider the results purely mechanical.

Nothing could exceed the interest that would

arise from the possibility of discovering the cause of life in animals. All the previous discoveries of philosophers would fall before such an acquired knowledge, and the gradual approximation of finite to infinite knowledge would glorify human intellect to an extent previously unimagined. It is hence that so many attempts have been made to assign electricity or magnetism, or both, as a cause of life—the hasty pride of mankind desiring to find out, and even account for, that which is not only as yet barely studied, but which even, in respect to organs and functions, is simply in an elementary condition, so far as science is concerned.

Wilson Philip was amongst the earliest to draw, practically, attention to the analogy of nervous and electric action; and his investigations led to the idea that the nerves of the body have an analogical influence to that of the conducting wires of a voltaic battery.

An able article in the first edition of Noad's *Lectures on Electricity, &c.*, thus places that physicist's views by way of epitome. The original account was inserted in the *Philosophical Transactions of the Royal Society.*

"In his earlier researches, he endeavoured to prove that the circulation of the blood, and the action of the involuntary muscles, are independent of the nervous influence. In a paper, read in January, 1816, he showed the immediate dependence of the secretory function on the nervous influence. The eighth pair of nerves distributed to the stomach, and subservient to digestion, was divided by incisions in the necks of several rabbits; after the operation, the parsley which they ate remained without alteration in their stomachs, and the animals, after evincing much difficulty in breathing, appeared to die of suffocation. But when in other rabbits, similarly treated, the galvanic power was distributed along the nerve below its section, to a disc of silver placed closely in contact with the skin of the animal opposite to its stomach, no difficulty of breathing occurred. The voltaic action being kept up for twenty-six hours, the rabbits were then killed, and the parsley was found in as perfectly digested a state as that in healthy rabbits fed at the same time; and their stomachs evolved the smell peculiar to that of rabbits during digestion. These experiments were several times repeated, with similar results.

"Thus a remarkable analogy is shown to exist between the galvanic energy and the nervous influence, the former of which may be made to supply the place of the latter, so that while under it, the stomach, otherwise inactive, digests food as usual.

"Dr. Philip was next led to try galvanism as a remedy in asthma. By transmitting its influence from the nape of the neck to the pit of the stomach, he gave decided relief in every one of twenty-two cases, of which four were in private practice, and eighteen in the Worcester Infirmary. The power employed varied from ten to twenty-five pairs.

"These results of Dr. Philip were afterwards confirmed by Dr. Clarke Abel of Brighton (*Journ. Sc.*, ix.) This gentleman employed, in one of the repetitions of the experiments, a comparatively small, and in the other a considerable power. In the former, although the galvanism was not of sufficient power to occasion evident digestion of the food, yet the efforts to vomit, and the difficulty of breathing (constant effects of dividing the eighth pair of nerves), were prevented by it. The symptoms recurred when it was discontinued, but vanished on its re-application. 'The respiration of the animal,' he observes, 'continued quite free during the experiment, except when the disengagement of the nerves from the tinfoil rendered a short suspension of the galvanism necessary during their re-adjustment. The non-galvanised rabbit wheezed audibly, and made frequent attempts to vomit. In the latter experiment, in which greater power of galvanism was employed, digestion went on as in Dr. Philip's experiments.

"It had been suggested by an eminent French physiologist, M. Gallois, that the motion of the heart depends entirely upon the spinal marrow, and immediately ceases when the spinal marrow is removed or destroyed. But Dr. Philip rendered rabbits insensible by a blow on the occiput; the spinal marrow and brain were then removed, and the respiration kept up by artificial means; the motion of the heart and circulation were carried on as usual. When spirit of wine or opium was applied to the spinal marrow or brain, the rate of circulation was accelerated.

"The general inferences deduced by Dr. Philip from his numerous experiments were, that voltaic electricity is capable of effecting the formation of the secreted fluids when applied to the blood, in the same way in which the nervous influence is applied to it, and that it is capable of occasioning an evolution of heat from arterial blood. When the lungs are deprived of nervous influence, by which their function is impeded or even destroyed; when digestion is interrupted by withdrawing this influence from the stomach, these two vital functions are renewed by exposing them to galvanic influence: hence galvanism seems capable of performing all the functions of the nervous influence in the animal economy; but obviously *it cannot excite the functions of animal life, unless when acting on parts endowed with the living principle.*"

On the question of a muscular electric current, the authority we have just quoted makes the following remarks—

"A proof of the existence of an electric current circulating through the muscle of a living animal, is obtained by introducing into a wound, formed in the muscle of a living animal, the nerve of a prepared frog, in such a manner that the extremity of the nerve shall touch the bottom of the wound, and at another point the edge. The frog instantly contracts. The muscular electric current may be detected in animals for some time after death; but, when it has once ceased, it cannot be renewed. It is found in warm as well as in cold-blooded animals.

"By forming a muscular pile, Matteucci succeeded in causing a considerable deflection of the needle of a galvanometer. Five or six frogs were prepared and cut in half, great care being taken not to injure the muscle. The thighs were then cut in half, and so disposed that each half thigh should touch the following, the faces of each turning the same way, and the interior of one coming into contact with the exterior of the next; so that one of the extremities of the pile was formed of the interior of the muscle, whilst the other was formed of the surface. The prepared plates of the galvanometer were immersed in the cavities of the board on which the pile was disposed, which cavities contained a liquid similar to that in which the plates had been prepared. The deviation of the galvanometer amounted to 15° up to 60°, according to the number of half thighs; and, if the frogs were sufficiently active, a deviation of from 2° to 4° was obtained with two elements; of from 6° to 8° with four elements; of from 10° to 12° with six elements; and so on in continued proportion dependent on the number of elements. The liquid in the cavities was distilled water; but when a liquid of better conductibility was employed, the deviations were considerably greater, though always in the same direction—namely, from the interior of the muscle to its surface. On leaving the circuit closed, the needle gradually returned to zero."

It is evident, therefore, that electricity is, in some forms, an element of nervous action. We cannot help arriving at such a conclusion; for, as already stated, and as, to some of our readers, the fact will be most familiarly known, the passage of an electric current by the nerves of the body at once produces most powerful muscular contractions. It, indeed, under such circumstances, takes the place of volition in causing the most powerful contractions of the muscular parts of the body; hence the violent effects of the electric shock, as caused by the Leyden jar, the voltaic battery, or the various forms of the inductive coil.

As a stimulus to vital action, either suspended or in its normal state, electricity has long been recognised as of great value. For example, in cases of drowning and others, arising from asphyxia, various forms of electric excitement have been beneficially employed. In all such instances we employ electricity simply to stimulate nervous action by an excitement of the nervous system. Some very sensible remarks on this subject are given by Dr. Noad, in his *Manual of Electricity*. He observes—

"The principal differences indicated by experiment between the action which is excited on the nerves by the electric currrent, and that excited by other stimulants, may be summed up thus:—

"The electrical current, according to the direction in which it traverses a nerve, has *alone* the power of exciting separately, sometimes contractions, sometimes sensation.

"The electrical current *alone*, while traversing a nerve transversely, produces none of the phenomena due to the excitability of the nerve.

"The electrical current *alone* produces no effect when its passage through a nerve is continued.

"The electrical current *alone* occasions the continuation of the excitement of a nerve after its action upon it has ceased.

"The electrical current *alone* possesses the power of re-establishing the excitability of a nerve, when it is transmitted in a direction contrary to that of the current which had destroyed or weakened its excitability.

"The electrical current is, of all stimulants, that which possesses, for the longest time, the property of arousing the excitability of a nerve, however weak it may be, compared with other stimulants."

We must, from the limited space at our disposal, conclude these remarks on animal electricity by a summary of Matteucci's conclusions on the subject.

"Let it be admitted that the electrical current, which traverses a nerve in the direction of its length, determines a derangement in the direction of this current, as the experiments of Porrett and Becquerel have proved; let it be admitted that this derangement is accompanied by vibratory movements of the nervous fluid, which are propagated to the extremity of the nerve, parallel to the direction of the organic derangement. This current of the nervous fluid produces *sensation* if directed from the extremities towards the brain; and *contraction* if directed from the brain towards the extremities. From this it follows, that an electric current traversing a nerve *normally* can produce no phenomenon. The direct current produces contraction when it enters, and sensation when it ceases. The inverse current, on the other hand, produces sensation when it enters, and contraction when it ceases. The phenomena observed during the first period of the vitality of the nerve, show that when the organic disposition of the nerve is perfect, its molecules are deranged in every direction by the application of any kind of stimulant, but always more so in the direction of the electric current than in the opposite direction. In proportion as the structure proper of the nerve ceases to be perfect, the phenomena produced by the current are those which take place in the direction in which this force acts with most intensity. Other stimulants produce in the structure of the nerve a derangement of a more permanent nature, and which, unlike that produced by the electric current, does not cease till the exciting cause is removed. An electric current which traverses a nerve for a certain time, finishes by permanently deranging its molecules; hence the reason why the prolonged action of the same current ceases, after a time, to produce its peculiar action on the nerve. A current in the contrary direction will bring back the molecules of the nerve into their former condition, and restore to them their capability of being excited by a current in the same direction as the first. The passage of an electrical current through a nerve in a different direction; the successive interruption of this current, and its greater intensity, are the causes

most likely to produce a permanent derangement in the structure of a nerve."

Here, with regret, we leave a most interesting subject, barely opened out to our readers. It is impossible to disbelieve that electricity has an enormous influence on animal and vegetable life. Still, we are at present much in the dark in regard to all or any of the conditions that exist between electric and nervous action. We know, as a fact, that such a relation exists; but, as yet, the amount of that relationship is hidden from us. It is pleasing to speculate on what *may be;* but it is difficult, and, indeed, unphilosophical, to take speculative views as explanatory of phenomena. Nothing can be of greater interest than to trace out the connection between mind and matter. But we have imposed upon us certain limits to the powers of investigation. Beyond these, at present, we cannot go. We therefore linger on the shore of that ocean of truth yet unexplored—not despairingly, but rather hopefully; for what we know not *now,* we shall know hereafter, and thus progress to a full knowledge of truth.

In the preceding Chapters, we have dealt with, in full detail, all the most important phenomena of electricity and magnetism. It has been shown how electricity of high tension, but of low quantity, can be generated by friction; that there are two forms of electricity thus produced: the *vitreous,* or that obtained by the friction of glass, etc., and the *resinous,* or that produced by the friction of resin and similar substances. The laws of conduction, insulation, and induction have been fully dealt with. It has been shown that electricity of great quantity, but of low tension, may be produced by chemical action, as in the voltaic battery, and that the current or dynamic force thus generated may be applied to the production of magnetism, in what was previously non-magnetised iron. The science of electro-magnetism, which springs from this fact, has been fully detailed in all its relations, but only incidentally as regards its applications. It has been seen, however, that by means of electro-magnetism, all the phenomena of frictional and chemical or voltaic electricity may be simultaneously produced, as by Rhumkorf's coil and other forms of *inductoria,* as such instruments are now called. The phenomena of magneto-electric induction, by which current and intense electric force may be so largely produced, has, with magnetism, received special attention, for on the application of these laws depend some of the most important applications of the electric force at the present day. The more recondite subject of dia-magnetism, by which we learn much of the peculiar affections of matter in relation to magnetism, with other subjects, have also been discussed and illustrated.

But hitherto we have only dealt with the applications of electricity in daily life, with the exception of electro-metallurgy (which has been treated *in extenso*), in a very general manner. The subsequent Chapters will unfold some most remarkable applications of the electric force, including the electric light, electricity as a motive power, the electric telegraph, etc., etc. During the greater part of the present century these applications were absolutely unknown. When they successively appeared their application was very gradual. But during the period of say from 1875 to 1882 they made such progress as has never been equalled in the history of science. The electric telegraph was wonderful, but the telephone and microphone, by which we can speak through miles of wire, eclipse its wonders. Again, the electric light in the period just named has been so largely adopted that the gas companies actually feared, and with some reason, that their monopoly would cease. Now, the electric light is nearly as common as the gas-light. Last of all, electricity as a motive power is an accomplished fact, and by it we can actually convey power for threshing wheat, driving machines, and a host of other such purposes, to any reasonable distances, say from a waterfall, through a thin copper wire for miles, and thus first convert motion into electricity, and this electricity, after travelling great distances, into motion again, as a means of power, wherever man may require. These matters will form the subject of the following Chapters, and they may justly be considered as the most magnificent triumph which the human intellect has yet made in dealing with natural forces, and applying them to human industry and social progress.

CHAPTER XVI.

THE ELECTRIC TELEGRAPH.

THE invention of the electric telegraph must, without the least hesitation, be ranked as marking an epoch in the history of man. From the confusion of tongues at the building of the Tower of Babel, up to the diffusion of tongues of the nineteenth century, there has never occurred a means of intercommunication in any way approaching the universality of the electric telegraph.

Our earliest forefathers in these islands, and, generally speaking, every nation having the slightest claim to be in the least civilised, have attempted some means of intercommunication through space. But in a chronology of four thousand years, how small a portion of that period has been characterised by anything that can be justly called a telegraphic system.

Fires on the hill-top seem to have been one among the earliest methods that were employed for that purpose; and even yet such plans are neither, in fact nor figuratively, extinct. In early days, when our islands were peopled by semi-savages, when the arts of civilised life were not only unknown, but, if they had been known, they would have been despised as effeminate—the rudest contrivances were had recourse to for the purpose of communicating intelligence.

It is a matter of curious speculation, how, in the earlier stages of our world's history, humanity contrived to get on without posts or telegraphs. The student of classical writers—such as Xenophon, Juvenal, Pliny, and their contemporaries—may imagine the difficulties that must have occurred, when those men of history flourished, in regard to the diffusion of general information. *They* had no post, no telegraph, no Reuter; and yet the arts greatly flourished, and, to a certain extent, some of the sciences, especially astronomy; which, by the way, of all others, requires, for its basis and establishment, an intercommunication of facts, opinions, and theories.

Horace tersely observes, "that it is not every man's good fortune to get to Corinth. *Non cuivis, &c., &c.*"—a remark which shows that the comparison of ideas between educated men, in his day, was limited to few privileged persons.

But even in our own day, despite all our advantages, the means of intercommunication—in Africa, for example—reflect no credit on scientific and commercial enterprise. As will eventually be shown, we have done much; but it will be also seen that much has yet to be done. Nearly four-fifths of the dry land of our globe, including Africa, Asia, and Southern America, are as yet destitute of those common means of intelligence-transit that Europe enjoys. Our rejoicing at the comparative advantages *we* possess, must, therefore, be controlled or modified in respect to what has not yet been accomplished. But we are rapidly advancing.

It would be a most interesting inquiry to enter on in respect to the earliest and quickest methods that were adopted to communicate important matters to distant places. We have already noticed the plan of beacon fires, which, however, must have been simply indicative, rather than descriptive. We can easily imagine that, by pre-arrangement, signals might have thus been passed from hill to hill. In our own day we have seen this done; but only a positive or negative result could thus have been arrived at—no detailed information could have been communicated.

But such inquiries, interesting as they may be to the antiquarian, have little to do with the subject that we have now in hand, except so far as historical detail goes; and for this we must refer our readers to works of a different class to our own.

In the early part of the present century, the old semaphore system of telegraphy existed. Many of our readers, in common with ourself, will remember an odd-looking erection at the "Horse-Guards," in Parliament Street, entering on St. James's Park; which, by differently extended arms reaching horizontally from a vertical pole, conveyed information to Portsmouth or other distant stations, by means of intermediate arrangements of a similar kind. The same system, modified in detail, is still maintained between ships by the use of flags having definite numbers, and referrible to a general index or register. Hence we read of ships "speaking to each other;" in other words, by means of signs mutually understood, two vessels can hold intercommunication where passage of boats between them is physically impossible.

On all our railways, at the present day, a modified system of such telegraphs still exists. The traveller cannot help noticing, during his journey, that, during day-time, an arm of the semaphore is elevated or depressed, to signify danger, caution, or safety, in respect to the driving of the train in which he is travelling. At night, a red, green, or white light takes the place of the elevated or depressed arm of the semaphore, denoting signals identical with those just mentioned.

But our daily experience teaches us that many conditions may interfere with the success of such signals. A slight amount of haze or fog renders them useless. At the present rate of railway travelling speed, should a fog occur, danger would not, nor could be indicated before

its effects were experienced. Now, those who remember the early days of railway travelling, cannot fail to have noticed that this system was that which necessitated the introduction of such a method of telegraphy as should be independent of all atmospheric conditions.

We were amongst the earliest travellers by the then London and Birmingham, but now the London and North-Western Railway. About forty years ago, the prejudice against locomotives entering a town was so great, that the company to which we refer were compelled to draw a train from Euston Square to Camden station, by means of a rope, set in action by a powerful steam-engine situated at the Camden station. Of course, it was a matter of the utmost importance that communication should be quickly made between the two stations, distant about a mile and a-half apart. This was, at first, effected by means of a pneumatic telegraph; that is, by compressing air at one station, through pipes passing to the next, signals were communicated. So far as our memory serves, this was the first form of telegraphic communication adopted on railways.

We may justly conclude that the introduction of the railway system was the cause of the energetic application of a new telegraphic system, founded on the mutual action of electricity and magnetism. One necessity in human life leads necessarily to another. We have heard from a forefather, that a three days' and nights' journey to Edinburgh was a speed that was not more than consistent with safety; and equally remember that goods arriving from Manchester in London in two days, were charged at a very high rate for "express" speed of travelling. An aged relative undertook the perilous journey of an excursion to Berkhampstead from London, and back, in the first year that the London and Birmingham line was opened; being previously warned that the speed at which the train was advertised to travel was neither more nor less than tempting or trying Providence. Many of our readers will remember, in their youthful days, "seeing off" the mail-coaches that, nightly at eight o'clock, left London in all directions. *They*, at that period, were the only safe and certain means of communication between distant places. But how have things changed since Œrsted first discovered that an electrified wire could deflect a magnetised needle, and Faraday discovered electro-magnetic laws, the induction of electricity by magnetism, and of the latter by electricity! In such discoveries, the doctrine that there is nothing new under the sun has its refutation. Gradually, from small beginnings, as between the Euston and Camden stations of the old London and Birmingham Railway, the telegraphic wire became extended from town to town. It was found that it might be submerged in the water of a river without (proper precautions being observed) injuring its capabilities. This led to a successful attempt to connect the English and French coasts by a submarine wire; and the success so obtained caused the construction of longer submarine wires between England and Ireland, and continental Europe. The Mediterranean was also successfully "cabled," if we may coin a new term. But the boldest of all the schemes that have yet been attempted, was that of connecting America and Ireland by means of a submarine cable. The attempt was at first both costly and a failure; but the interest the brief success induced, would not permit British enterprise to be beaten in the long run. Omitting the circumstances and causes of early Transatlantic failure here (deferring them to our future pages), it may be simply remarked, that now several cables stretch between the Old and New Worlds, conveying scores of messages instantaneously, working to the satisfaction of shareholders and customers, and bringing in a pecuniary return that is almost fabulous. Again, our possessions in the East Indies have been placed in full electrical connection with the metropolis; and, at the present time, Bombay, Calcutta, Madras, and other Indian cities, China, Japan, Australia, etc., on the coast and inland, are, electrically, within a few hours only distant from each other. It is now possible, although not always practically realised, that the western coast cities of Hindostan may be as readily communicated with as Liverpool, Manchester, New York, etc., are in respect to London.

We are indebted for some of the following early historical account of the electric telegraph to Mr. Noad's admirable *Manual of Electricity* (edition 1855—'57). He remarks, that, in 1747, Dr. Watson, the celebrated Bishop of Llandaff—so famous for his general learning, as also for scientific attainments—made, with several other philosophers, experiments at Shooter's Hill, near Woolwich, which showed that electrical charges from a Leyden jar could be propagated through a distance of upwards of four miles, without any appreciable difference in the lapse of time occurring between the discharge and its effect, although a considerable portion of the circuit was formed of land and water.

As we shall subsequently more fully point out, the qualities of frictional electricity are such as to render it most ineligible as a source of power for telegraphic purposes. Nevertheless, the success of Dr. Watson led to other attempts; such as those of Winkler at Leipsic, in 1750; Le Moutier at Paris; and Betancourt at Madrid, the latter sending discharges through a circuit of twenty-six miles.

Mr. Noad considers that "the first distinct proposition to employ electricity as a mode of telegraphic communication, appears to have originated with Lesage, who, in the year 1774, established at Geneva an electric telegraph, consisting of twenty-four metallic wires well insulated from each other, and each in communication with a small pith-ball electrometer, which could be diverged by an electrical machine, and caused to point to a letter or other conventional signal; and by this means a communication between two distant places was proposed to be established." Others followed in the same steps; but, as voltaic electricity was then unknown, although a modicum of success was obtained by the electrical machine and Leyden jar, it was so

partial and difficult of realisation, that, practically, the results were valueless; and, consequently, no beneficial application immediately followed.

Mr. Ronalds, of Hammersmith, in 1816, made a further step in the right direction. He also employed frictional electricity, and a pith-ball electrometer, the signals being effected by the divergence of the pith balls as the charge affected them, and by their collapse as the discharge ceased, or the electricity returned to a state of equilibrium. He showed that a telegraphic system might be founded on the employment of electricity for that purpose, and endeavoured to interest the government in the subject; but the sapient legislators of those days considered, "that telegraphs of any kind were then wholly unnecessary [the continental war having been closed, which, we presume, was the reason of this reply], and that no other than the one then in use would be adopted."

Ronalds, like many other inventors, being thus imperiously bowed off, seems to have, after the description of his invention in 1823, made no further progress. The great discovery of this period was that made by Œrsted in 1819-'20—we mean the deflection of a magnetic needle by a wire conveying a voltaic current—that afterwards, in the hands of Cooke and Wheatstone, formed a really and long-used form of electric telegraph actuated by the voltaic current. But of this more will be said in the proper place, as we are now dealing with the historical rather than the descriptive portion of our subject.

Mr. Noad accords to Soemmering the merit of producing the first electro-chemical telegraph, which was described in 1812. The inventor employed thirty-five gold points, immersed in dilute acid; and these were arranged to correspond with thirty-five brass plates. The latter was the receiving apparatus, whilst the wires immersed in the acid were the recording apparatus. As soon as the pole of a voltaic pile was placed in contact with one of the brass plates, the corresponding gold point in the recording arrangement evolved gas, and indicated any chosen letter; and thus, by evolving gas from any set of chosen points, to each of which a letter of the alphabet was assigned, it was possible to spell words, with a tolerable amount of certainty, at a distance from the battery, &c.

By this and all the previous arrangements a separate wire was required for each letter; and hence, had the plans that were thus proposed been as efficient in results as those we obtain by our most improved modern instruments, still the expense of the wire between any two distant places would have been very great, and would also be largely added to in the intermediate arrangement of hanging, &c. In those days, india-rubber, gutta-percha, ebonite, and other modern insulators, were unknown; the voltaic batteries were of the most imperfect construction; and, in fact, we may sum up the whole of the electro-telegraphic circumstances of that period, by saying that they possessed hardly a single qualification of battery power, material for insulating, and nearly every other condition now considered as absolutely essential for such purposes.

Ampère seems to have been the first to suggest a practical application of Œrsted's discovery, made in 1819. In the following year he suggested to the Royal Academy of Sciences, at Paris, that, by means of a set of needles and conducting wires, equal in number to the letters of the alphabet, signals might be communicated, by the deflection of those needles, by means of the voltaic current.

Gauss and Weber appear to have been the first to have employed a current of magneto-electricity in place of the voltaic one; that is, in 1836. This method was subsequently adopted by the Magnetic Telegraph Company, that, for a long time, worked their lines by electricity induced by magnetism. Steinheil invented a printing and sounding telegraph, that was at work in 1837.*

We next revert to Mr. Morse, an American inventor, whose claims to telegraphic improvement rank as high as those of any one who has investigated the subject, and reduced it to practice. Much will have to be said hereafter of the instruments invented by Morse. It seems that he first conceived the idea of an electric telegraph in 1832, but did not reduce that idea to practical purposes until 1837. But we much prefer that our readers should judge of Morse's merits by consulting the work of one of the most able of American telegraphists, Colonel Shaffner, who, in his volume on *Electro-Telegraphy*, has almost exhausted the historical part of the subject, as may be well imagined when we state, that he has attempted to trace the pursuit and possession of the art from the earliest ages of the history of man, to the date of the publication of the work just referred to.

We now turn, with mingled feelings of pain and pleasure (omitting useless forms of the telegraph that had been invented), to the great improvements of Cook and Wheatstone, both of whom were knighted, as an acknowledgment of their services in the art, and both are now deceased.

Those gentlemen took out various patents antecedent to 1845; but it was in this year that they patented the needle telegraph—first the single, and, subsequently, the double-needle instrument—which soon became adopted at every telegraph station in these islands.

We do not propose to enter in the least into any questions that affected personally Messrs. Cooke and Wheatstone, as our pages must be devoted to a much better purpose. We shall avail ourselves, however, of extracts from a work by Mr. William Fothergill Cooke,† that he published for the purpose of pointing out his claims to originality; but shall only do so as far as it elucidates the history of the electric telegraph.

* In a following Chapter there will be given a full description of the different forms of magneto-electric machines as used for the electric light, etc.

† *The Electric Telegraph. Was it Invented by Professor Wheatstone?* The work was published simultaneously in two editions—viz., as a volume and a pamphlet.

First in order, we quote Professor Wheatstone's observations as to the cause which led him to take up electro-telegraphy. He says—

"When I made, in 1823, my important discovery that sounds of all kinds might be transmitted perfectly and powerfully through solid wires, and reproduced in distant places, I thought that I had the most efficient and economical means of establishing a telegraphic (or rather a telephonic) communication between two remote points that could be thought of. My ideas respecting establishing a communication of this kind between London and Edinburgh, you will find in the *Journal of the Royal Institution* for 1828. Experiments on a larger scale, however, showed me that the velocity of sound was not sufficient to overcome the resistances, and enable it to be transmitted efficiently through long lengths of wire. I then turned my attention to the employment of electricity as the communicating agent; the experiments of Ronalds and others had failed to produce any impression on the scientific world: this want of confidence resulted from the imperfect knowledge we possessed of the velocity and other properties of electricity; some philosophers made it a few miles per second, others considered it to be infinite: if the former were true, there would not be much room for hope; but if the velocity could be proved to be very great, there would be encouragement to proceed. I undertook the inquiry, and with the result the whole scientific world is acquainted. At the same time I ascertained that magnetic needles might be deflected, water decomposed, induction sparks produced, &c., through greater lengths of wire than had yet been experimented upon. In the following year, at the request of the Royal Society, I repeated these experiments with several miles of insulated wire, and the results were witnessed by the most eminent philosophers of Europe and America. I ascertained experimentally (which had never been done before) many of the conditions necessary for the production of the various magnetic, mechanical, and chemical effects in very long circuits; and I devised a variety of instruments by which telegraphic communication should be realised on these principles."

In respect to the discovery of the rapid conduction of sound through solid bodies, we may add, that, in 1855-'56, Wheatstone's discovery was turned to practical account at the Polytechnic Institution, Regent Street, London, in the production of what was called the "telephonic concert." Any musical instrument, say a piano, was placed in the basement of the building, and on the sounding-board of the piano rested a deal rod, which was continued vertically through the entrance-hall to the front lecture-room, a distance of fifty or sixty feet. The sound of the instrument, when played on, was quite inaudible in the lecture-room until some diffuser of sound was placed on the rod; such as a harp, violin, or even a wooden box. At that moment the sound was heard almost as distinctly up-stairs as if the piano had been there. By modifications in detail, other instruments gave similar results; and ultimately, Mr. Pepper (the lessee of the institution), together with the author of this work, succeeded in conveying the human voice, and quartets were thus transmitted acoustically from one part of the building to another.

Now, at first sight, this would seem to have little connection with electro-telegraphy; but those who understand the laws of the undulatory forces, will fully appreciate what Wheatstone says—that, after discovering this rapid conduction of sound by solids, "I thought that I had the most efficient and economical means of establishing a telegraphic (telephonic) communication between two remote points that could be thought of."

In February, 1837, Messrs. Cooke and Wheatstone first became acquainted; and, in May of that year, they conjointly took out a patent for an electro-magnetic telegraph, and for some time those gentlemen worked well together. But perfection is not an attribute of humanity, and by 1840 many differences arose between them. The matter was at last referred to two of the most eminent men of science of the day—Sir Isambard Brunel, the originator of the Thames Tunnel, and of many eminent engineering and other works; and Professor Daniell, of King's College, London, the inventor of the constant battery that bears his name. As the disputes in question have become matters of history, and are still on the *tapis*, we feel compelled to notice them thus briefly; and to conclude our remarks on them by quoting some portions of the award made by the eminent men above named, and which certainly ought to have settled for ever this painful subject.

Sir I. Brunel and Professor Daniell thus state the case:—

"In March, 1836, Mr. Cooke, while engaged at Heidelberg in scientific pursuits, witnessed, for the first time, one of those well-known experiments on electricity, considered as a possible means of communicating intelligence, which have been tried and exhibited from time to time, during many years, by various philosophers. Struck with the vast importance of an instantaneous mode of communication to the railways then extending themselves over Great Britain, as well as to the government and general purposes; and impressed with the strong conviction that so great an object might be practically attained by means of electricity, Mr. Cooke immediately directed his attention to the adaptation of electricity to a practical system of telegraphing; and, giving up the profession in which he was engaged, he, from that hour, devoted himself exclusively to the realisation of that object. He came to England in April, 1836, to perfect his plans and instruments. In February, 1837, while engaged in completing a set of instruments for an intended experimental application of his telegraph to a tunnel on the Liverpool and Manchester Railway, he became acquainted, through the introduction of Dr. Roget, with Professor Wheatstone, who had, for several years, given much attention to the subject of transmitting intelligence by electri-

city, and had made several discoveries of the highest importance connected with this subject. Among these were his well-known determination of the velocity of electricity when passing through a metal wire; his experiments, in which the deflection of magnetic needles, the decomposition of water, and other voltaic and magneto-electric effects, were produced through greater lengths of wire than had ever before been experimented upon; and his original method of converting a few wires into a considerable number of circuits, so that they might transmit the greatest number of signals, which can be transmitted, by a given number of wires, by the deflection of magnetic needles.

"In May, 1837, Messrs. Cooke and Wheatstone took out a joint English patent, on the footing of equality, for their existing inventions. The terms of their partnership, which were more exactly defined and confirmed in November, 1837, by a partnership deed, vested in Mr. Cooke, as the originator of the undertaking, the exclusive management of the invention in Great Britain, Ireland, and the colonies, with the exclusive engineering department, as between themselves, and all the benefits arising from the laying down of the lines, and the manufacture of the instruments. As partners standing on a perfect equality, Messrs. Cooke and Wheatstone were to divide equally all proceeds arising from the granting of licences, or from sale of the patent rights; a per-centage being first payable to Mr. Cooke, as manager. Professor Wheatstone retained an equal voice with Mr. Cooke in selecting and modifying the forms of the telegraphic instruments; and both parties pledged themselves to impart to each other, for their equal and mutual benefit, all improvements, of whatever kind, which they might become possessed of, connected with the giving of signals, or the sounding of alarms, by means of electricity. Since the formation of the partnership, the undertaking has rapidly progressed, under the constant and equally successful exertions of the parties in their distinct departments, until it has attained the character of a simple and practical system, worked out scientifically on the sure basis of actual experience.

"Whilst Mr. Cooke is entitled to stand alone, as the gentleman to whom this country is indebted for having practically introduced and carried out the electric telegraph as a useful undertaking, promising to be a work of national importance; and Professor Wheatstone is acknowledged as a scientific man, whose profound and successful researches had already prepared the public to receive it as a project capable of practical application—it is to the united labours of two gentlemen so well qualified for mutual assistance, that we must attribute the rapid progress which this important invention has made during the five years since they have been associated:" that is, from 1837 to 1841, in which latter year the preceding award was made.

It does not seem that telegraphy made much progress up to the year 1843; as, according to Mr. Cooke, the importance of a telegraph in connection with a single line of rails had only attracted the attention of engineers in 1842: and he says—"At the beginning of the year 1843, we were at our lowest point of depression. The patents remained almost unproductive; and we had incurred, in various ways, a considerable outlay." Gradually, however, as the railway system expanded, it became necessary to have some means of communication between distant stations, to prevent accidents, which occurred frequently through ill-timing of trains. Again, on certain lines, there were special circumstances that made telegraphic communication absolutely necessary. For example, the London and Birmingham line was worked with ropes between Euston and Camden stations; as was also the Blackwall line, the Lime Street end of the Liverpool and Manchester line, with others that subsequently sprung up. In all such cases it was absolutely essential that each station should be informed of the moment when the engine that drew the rope was to start. Many of our readers will remember the source of annoyance to business that frequently occurred on the Blackwall line through breakage of the rope, owing to irregular strain being put upon it. Others, who then took an interest in telegraphic matters, will also remember that the electric telegraph wires first laid down on that line, were enclosed in an iron tube, hung by staples in the side walls of the line; for, at that period, the plan of suspending the wires on poles had not been thought of. Indeed, it was considered that such a method would destroy all insulation of the wires. This turned out, subsequently, to be as a great an error as was committed in the case of early locomotives. It was imagined that the wheels of the engine would not "bite" the rails; or, in other words, that they would slip round, and so afford no motive capability. Hence several patents to obviate this difficulty (which, however, did not exist) were taken out.

The prosperity year of 1845 led to a great development, simultaneously, of the railway and telegraphic systems; and, towards the close of that year, the telegraph had spread to most of the leading lines in the country. In fact, the progress of both systems was simultaneous. About that period it was proposed to establish the Electric Telegraph Company, which was constituted in 1846. The following interesting particulars of the history of this company have been extracted from *Engineering*, by permission of the editors.

"In the very commencement the lines were erected partly by the company and partly by contract, in hurry, and under all sorts of arrangements; but, for some years afterwards, the lines were constructed entirely under contract, and even maintained by agreements, not for a week or a month—like a submarine cable under the conditions of those excellent 'provisional contracts,' which innocent directors of new companies have so often indulged in with contracting firms and companies—but for a term of years. It was soon found, however, that the company could construct their lines much more cheaply themselves, and maintain them, not only at less cost, but more efficiently. The pioneers in the

electrical and engineering department of the company—Cooke, Wheatstone, Hatcher, and Physick—must in those early years of telegraphy have had many difficulties to contend with. The insulation at first was effected by little double cones of earthenware, separating the wire from a staple fastened to the pole; and was, of course, very imperfect. The ponderous winders at every half mile or so, attached to a great bolt going through the pole, and only insulated by a collar of earthenware, must also have given a leakage to the current about equal to what a two-inch hole at every half mile in a three-inch water-pipe would give; and the plan of grouping the wires on to vertical arms, which were again imperfectly insulated from the pole, was admirably adapted for producing 'contact;' that is (in popular language), the current, instead of leaking to earth, leaked into the other wires, thus producing a jumble of signals on all the circuits in contact, something like the confusion in conversation produced by a dozen young ladies talking at once. Contact is far more difficult to prevent, and far more serious, than merely a 'little earth'—that is, a little leakage to earth—as the latter can be 'worked through' by applying more battery power; but contact cannot be so easily eliminated.

"In those days there were no testing instruments, except a rude galvanometer, commonly known as a 'detector;' and though Ohm wrote his treatise in 1827, his laws layed buried fathoms deep in the pages of *Scientific memoirs* for many years even after this date. Resistance coils were not known, and the only means of finding a fault was by trudging along the line, weather or no weather, until the cause was perceived. One fault in those dark ages that we have heard of is worthy of notice. A contact between two wires invariably came on at certain hours in the day only, and that only in fine weather. It was a stumblingblock for weeks, and was eventually discovered to be caused by the metal edge of a cottage hinged window, which was opened in the morning or evening in fine weather, and thus touched two of the wires.

"Mr. Physick, the assistant engineer, improved the insulation in 1847, by adopting an earthenware inverted cup, with a hook below supporting the wire, a complete zone of the earthenware being thus protected from the rain. This, though not the earliest inverted cup-insulator *patented* (for Brett and Little's, which was precisely similar to the present Prussian insulator, was patented February 11, 1847; whilst Physick's, which is patented under the name of J. L. Ricardo, bears date only September 4, 1848), was the first used by the Electric Telegraph Company, and forms the first step in the direction of that mode of insulation which has since been so often varied and modified, each modification forming the subject of a lucrative patent.

"Mr. Edwin Clark, who became engineer to the company in 1850, improved the whole construction of the lines and instruments. Winders were abolished; round larch poles were adopted instead of the costly square foreign timber; and only twenty to twenty-two poles to the mile erected instead of thirty. Cross-arms, beneath each of which two insulators were attached, having a zinc cap, which protected more of the earthenware than in Physick's insulator, were introduced; and the lines, thus rendered less costly, and improved in their insulation, were, by Mr. Clark's energy and ability for negotiation, extended to nearly double their previous extent, under agreements with the various railway companies.

"The instruments—though still the original double needle of Cooke and Wheatstone—were disencumbered of their ponderous and expensively ornamented rose-wood frames, and the neat modest little instrument still seen in our railway stations, with green fronts and circular cover, adopted. The frames were so made that, by removing the cover, the coils and contact-pieces could be got at without having to go round to the back of the instrument, as in these first instruments. The coils were made so as to be easily 'unshipped' without using a screw-driver, either for the purpose of magnetising the needle or to replace a coil destroyed by lightning, spare coils for this purpose being provided.

"In 1852, the time-ball at the Strand office, which drops daily at one o'clock, being released by the action of a current sent from Greenwich, was erected at Mr. Clark's suggestion, according to his designs. The Observatory clock, by very simple mechanism, makes contact between the line wire and a battery; and the current, acting on a relay, completes a local circuit containing a battery and an electro-magnet in the room at the Strand office. The electro-magnet releases a trigger on which a projection on the rod of the ball rests, thus allowing the ball, which is previously raised by a winch and rope, to fall. The rod to which the ball is attached terminates on a piston plunging into an air cylinder, and the cushion of compressed air thus acts as a buffer to moderate its descent.

"In 1853, the company extended its lines to the continent, by the submergence of three cables from Orfordness to Scheveningen, in Holland, a distance of 114 statute miles. These cables proved too light for the locality; but the operations undertaken for their repair and maintenance, and the machinery and system adopted by Mr. F. C. Webb, are the earliest examples of this description of work; and this system has formed the basis of all subsequent operations of a similar nature, on still greater lengths and in deeper water—finally reaching, under the skilful direction of Sir S. Canning and Mr. Clifford, its present perfection in the repair of an Atlantic cable in 2,000 fathoms. These cables were the first on which the retardation of signals, previously noticed by Mr. L. Clark on subterranean wires in 1852, was studied and combated. To neutralise the charge more quickly, the current sent was followed by a reverse current of short duration; and the relay at the distant station was also so constructed as to make contact in the local circuit when a positive current was sent, and break contact with a negative current. Thus, instead of having to wait after each signal

until the charge had flowed entirely out of the wire, and the armature of the electro-magnet was thus released, the reverse current first neutralised the charge, and then, acting on the relay, broke the contact. The first relay of this kind was probably that made by Mr. Window, and submitted to Mr. Clark and Mr. Varley; but it does not appear to have been made with the object of overcoming the difficulty of retardation, but only as a new form of relay; and we believe that the perception of the advantage of reverse currents for overcoming retardation, and the elaboration in detail of the necessary keys and instruments for carrying out the idea at that date, are fairly due to Mr. C. F. Varley. Ireland was joined to England by a submarine cable for this company in 1854; and Mr. L. Clark, who had acted for four years as assistant engineer, became engineer in the same year. The insulation was now still further improved. The zinc caps of Edwin Clark's insulator had a hole in the top, through which the supporting bolt passed, and the interstices between the bolt and cap were only with great care and difficulty kept water-tight. Insulators, some of glass and others of earthenware, were therefore introduced, somewhat similar to Mr. E. Clark's, but in which the protecting inverted cup was cast or moulded all in one piece with the internal cylinder which supports the wire; thus the difficulty of keeping the cap water-tight was overcome. More care also was taken to obtain good material for insulation, free from pores, and thoroughly glazed. Both glass and earthenware gave place at last to white porcelain, in the form of *the double-cup* insulator, supported from below (similar to the Prussian insulator, or Brett and Little's, with the addition of a second cup inside), thus trebling the resistance of the film of wet which fog, or an atmosphere saturated with moisture, may deposit on the interior surface.

"Soot and dust are the great enemies to insulation of aërial wires; and dirty insulators in damp weather meaning bad insulation, this insulator was designed so that it could, for the purpose of changing dirty for clean insulators, be easily unshipped from the iron supporting brackets, which were adopted instead of the wooden arms.

"The wooden arms gave some amount of insulation in case of a broken or bad insulator; and it is very doubtful whether this change to iron supports is an improvement, as it renders the insulation so entirely dependent on the perfection of each and every insulator, particularly where iron poles are used, or where, there being more than one wire on wooden poles, it becomes necessary to avoid the possibility of contact by the attachment of an earth wire to every iron arm.

"The Bain (chemical marking) printing instrument, used on a very few circuits in 1852, had, in 1854, become more into use; whilst the Morse, with Varley's improvements, was used on the continent, although for the majority of the circuits the double-needle instruments were still employed. The gradual substitution of the Morse instruments, instead of the Bain and double needles, on most of the commercial circuits, was continued until 1858, from which time until 1863 the double-needle instrument was still more rapidly abolished, one of the wires of each double-needle circuit being frequently made into a single-needle circuit with intermediate stations, and the other being used for through circuits with Morse instruments.

"In 1858, a heavy four-conductor cable was laid from Dunwich to Holland; and the Hague cables, or a large portion of them, afterwards gradually taken up, and used for other purposes.

"The pneumatic system of sending messages to short distances, from the central office, was first adopted in 1854, under the designs of Mr. L. Clark; and, since that date, has been largely employed under such circumstances.

"Mr. C. F. Varley became engineer in 1861, and, as a matter of course, the insulation was once more altered. Brown earthenware was reinstated in lieu of white porcelain, but the double cup still adhered to, with this difference, that the cups were made separately, and the one cemented into the other. The insulating qualities of earthenware as a medium are very variable, depending on the pureness of the clay, and the degree of vitrification obtained; some samples are very porous. As a rule, therefore, earthenware depends for its insulating qualities as a medium—or, in fact, its resistance to conduction—greatly on the glaze on its surface, which, if good, may give all the resistance necessary, whilst the interior may be as porous as a sponge. But as this surface may easily get chipped or cracked, it will be seen that, as in Varley's insulator, there are four vitrified surfaces which must become broken instead of two, and two separate bakings of clay that must be porous to form a bad insulator, whilst three out of four of the surfaces are free from danger of chipping after the insulator is once constructed; the chance of having a good insulator, so far as the actual conduction through it as a medium is concerned, is greatly increased. The dry-surface insulation is the same as in Clark's. It should be remarked, however, that the manufacture of the white porcelain has been so perfected, that it is vitrified through so completely as to render the advantage and necessity for Varley's separate cups of brown earthenware very doubtful.

"The wooden arms were once more used instead of iron brackets; but the means for removing the insulator quickly are evidently not as effective as Mr. Clark's, as the supporting bolt is fastened through the arm by a nut and washer.

"In 1863, Digney's ink-printers, made and improved by Siemens, were substituted for most of the Morse instruments. In 1864, a cable, of the heaviest pattern ever made, with four conductors, was laid from Lowestoft to Holland, thus increasing the continental wires to eight—since increased to twelve by the Reuter Company's cable, laid recently to Hanover, and which is worked by the Electric and International Company.

"It may be readily imagined, from what has

been stated, that the improvements in insulation have been only attained at great cost; and there are those who would even maintain, that the happiest thing for the shareholders would be, to obtain an engineer who would not invent an insulator. This is hardly the spirit in which to view these matters. Each insulator has been an improvement, in some way, on its predecessor; and although the system of allowing paid officials to patent the result of their thought and labour—and, indeed, the thought and labour of those around them—has, perhaps, tended towards a somewhat bold outlay for the re-insulation of the lines, and also by securing a monopoly to the inventions of their own engineers, prevented any improvement that might have resulted from a free trade in the inventions of those unconnected with the company; yet we think that, viewing the whole case and the present results, so far as insulation is concerned, the directors can scarcely regret the liberality of their policy, in this respect, towards their immediate *employés*. The system has, however, its disadvantages, as it must naturally give their officers an interested view when considering the inventions of others. We will only here quote, as an instance of this, the exclusion from use, on the Electric Telegraph Company's system, of Hughes' type-printing instrument, now employed by the United Kingdom Company, the French and Russian governments, and which will soon, we hear, be still more extensively introduced on the continent."

We have already traced the early attempts that were made to use frictional electricity for telegraphic purposes, and pointed out how, necessarily, it must fail; and have also glanced at some of the most important inventions that were made up to 1837, in which the voltaic current was employed. But many of our readers will much value a kind of summary of the progress thus made; and the following particulars, with dates, &c., are afforded by Dr. Hamel, in his *Historical Account of the Introduction of the Galvanic and Electro-Magnetic Telegraph into England*; with comments thereon by Mr. Cooke. Dr. Hamel gives the following well-ascertained dates:*—

"1809. 8th July.—Soemmering invented his plan for telegraphing by evolution of gas.

"1810. 13th August.—Showed it to Baron Schilling, at Munich.

"1802. May.—Grandominco Romagnosi discovered that the magnetic needle was deflected by galvanic currrents; and in August, in the same year, published the discovery at Trent.

"1812.—'Baron Schilling's operations with a sub-aqueous galvanic conducting cord, through the river Neva, at St. Petersburg.'

"1815. 3rd August.—Baron Schilling communicated to Soemmering the *Manuel du Galvanisme*—a book printed at Paris in 1805, mentioning Romagnosi's discovery.

"Baron Schilling may, therefore, be supposed to have known from this date the fact, that a galvanic current deflected a magnetic needle; although Dr. Hamel comes to the conclusion, that neither Soemmering nor Schilling had any idea of a practical application of Romagnosi's discovery until 1825 or 1826—five years after Ampère's suggestion.

"1820.—Œrsted directed the attention of the scientific world, more effectually than Romagnosi had done, to the influence of a voltaic current on a magnetic needle. Dr. Hamel supposes him to have been acquainted with Romagnosi's discovery of 1802.

"1820.—Ampère suggests, 'that it might be possible to make use of the deviation of the needle for telegraphic purposes.'

"1824.—Scweigger invents the multiplier coil.

"1830. April.—Is the first clear date given by Dr. Hamel in connection with Baron Schilling's needle telegraph, when it was shown to the Emperor Nicholas; 'who (he adds) had been pleased to notice it in its earlier stage.' But the Doctor speaks vaguely of 'above a dozen years previous' to 1837 as the date of Schilling's invention.

"In 1830, Baron Schilling had known for twenty years the details of Soemmering's telegraph; and, for at least fifteen years, the deflective power of the galvanic current on the magnetic needle.

"1835.—Schilling shows his telegraph at Bonn, simplified to a single needle and multiplier.

"1835.—Müncke exhibits at Heidelberg, a model of Schilling's telegraph.

"1836. March.—Cooke sees Müncke's model of Schilling's one-needle telegraph.

"1836. March.—Cooke makes two instruments shown in the drawing, Part B, vol. ii., of Cooke's work on the telegraph; at the end, where they are compared with Müncke's models.

"1836. March.—Cooke invents the mechanical telegraph and alarum, in which signals and sounds are given by the removal of the detent of clock-work by the voltaic magnet. Also the detector.

"1836. April 22nd.—Cooke returns to England, to work out his scheme of realising the old idea of an electric telegraph.

"1837. January.—Negotiations between the Liverpool and Manchester Railway Company, for the use of his 'so-called mechanical telegraph.'

"1837. May.—The first electro-telegraphic patent applied for by Cooke and Wheatstone, for their joint inventions.

"1837.—'Baron Schilling ordered a submarine cable to be made to unite Cronstadt with the capital, through the Gulf of Finland, for telegraphic correspondence.'

"1837. 25th July.—'A trial was made at the terminus of the London and Birmingham Railway (then constructing), one mile and a quarter in length, from Euston Square to Camden Town. This was the first instance of outdoor telegraphing in England with a galvanic apparatus.' 'Mr. Cooke had been permitted, at the Euston Square terminus, in a large build-

* "The earlier dates of the telegraphic idea, by frictional electricity, go back to the middle of the last century; and are accurately traced in an article on the electric telegraph in the *North British Review* (January, 1855), to a Scotchman in 1755."

ing (the carriage-house), to suspend many miles of wire, along which the current was made to pass, besides the wires in the open air to Camden Town.'

"These facts and dates together will, perhaps, indicate to what countries, and in what relative proportions, the realisation of the galvano-electric telegraph is really due."

We have thus endeavoured to sketch out electric telegraphy until its historical part becomes merged in the descriptive. There are few instances, perhaps only one—that of photography—in which pure science has been so rapidly, completely, and extensively applied to the general purposes of mankind; and hence the subject presents features of the highest interest to every class of society, involving, as it does, so many important bearings on politics, commerce, and social life.

TELEGRAPHIC APPARATUS.

The consideration of this branch of our subject may be primarily divided into three classes—namely, instruments that produce the current of electricity; the means of conveying the current; and, lastly, the instruments that indicate the message. Simple as the first division appears, the variety of inventions that have arisen from the introduction of electro-telegraphy, renders it a by no means easy matter to explain the construction and use of a fraction of them that have been brought into practice. Although frictional electricity might be used for telegraphic purposes, practically it is of no avail. To use a popular description of the facts of the case, its effects are too instantaneous, and, consequently, fleeting. A little dust or moisture, damp air, and a variety of other conditions, immediately dissipate all the powers of static or frictional electricity. Even the flash of lightning, powerful as it is in nature, would, if it were collected by proper means (which could be done), be utterly unmanageable. In the present condition of electro-telegraphy, a steady, continuous, and long-travelling current is requisite. It must also be one that is not easily diverted from its course—one that will travel readily by a good conductor—such as a metallic wire, so long as that is continuous—but, at the same time, resist any accidental diversion of its course if want of good insulation occurs.

Practically, therefore, the voltaic current is the best for such purposes, although that derived from the magneto-electric machine has been, and always may be, employed. Either of these currents possesses all the requisites of the modern telegrapher. Sufficient quantity is easily acquired to actuate the electro-magnetic arrangements that are usually employed—that quantity being capable of increase to any desired extent by an increase of the size of the plates employed, or by using a stronger acid solution; whilst if the length of telegraphic wire through which the message be passed be great, and, consequently, the resistance to the passage of the current be large, then an increase in the number of battery cells at once overcomes the difficulty. As we shall subsequently see, our knowledge of the resistance of metallic wires, in respect to their section and area, is now so accurate, that a specific size of plate, and number of cells, may be assigned *à priori* to any length of telegraphic communication.

During the last forty years the voltaic battery has undergone great improvements. A modern battery, covering a surface of twelve inches each way, and six inches high, may be made to evolve more power of calorific, luminous, electro-magnetic, and other effects, than an equivalent series of batteries as employed by Sir H. Davy, and which in his time would, to produce the same effect, have covered the floor of a large laboratory. But the latter kind of batteries had their maximum effects for only a few moments, after which their power rapidly degenerated until it arrived at nothing. Batteries in modern use, by a little care, may be so arranged as to give, for months together, almost an exactly equal amount of power. Not only so, the method of amalgamation now universally practised in regard to the zinc element, prevents any loss of that metal until the moment of using the battery—a question not only of economy, but one essential to the continuous action of a battery. The contrast between the modern arrangement of the voltaic cell, and that of the older forms, finds an analogy in the steam-engine and horse. If a man possess a one-horse steam-engine, he lights the fire beneath the boiler at the time he requires the motive force; and when he has done with it the fire is put out. Consequently, the steam-engine is no source of expense except at the moment of its use; whilst the horse, whether he work an hour per week or the whole week, costs precisely the same; and hence, to use a common phrase, may soon "eat his own head off."

It will be unnecessary for us, at present, to enter into a description of all the batteries that have been invented for experimental and telegraphic processes; but a general glance at those most available for all such objects will be first desirable.

The simplest form of the voltaic battery* is that in which a plate of copper and one of zinc,

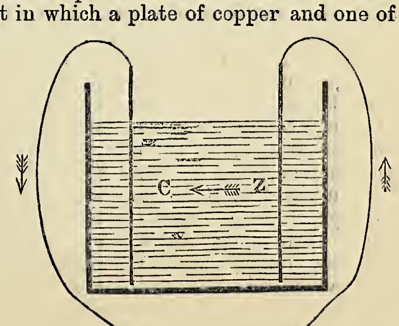


Fig. 266.—Simple Voltaic Cell.

immersed in an acid or saline liquid, are placed

* See p. 227, *ante*, for a full description of voltaic batteries, and the peculiarities of each.

face to face, but not touching each other. From each a copper wire proceeds; and on these wires being connected together, a current of electricity is generated, that passes from the zinc, *z*, to the copper, *c*, through the fluid, and from the copper back to the zinc, by the wire, in the manner shown in the preceding cut.

Precisely the same principle is involved in the construction of every form of voltaic battery, but the details are various. Owing to the slow escape and partial adhesion of hydrogen on the surface of the copper, in the simple battery just described, the power is, comparatively speaking, trifling, at least when other and improved arrangements are considered.

In all forms of voltaic batteries, three special points are to be considered. In the first place is the zinc or positive metal, that undergoes solution in all kinds of batteries, except that in which the gases hydrogen and oxygen are used with one metal or carbon. The electrical current generated is due to the action of oxygen in the water employed on the zinc of the arrangement; and the oxide of zinc is produced by this action. The acids employed have for their object the solution of the oxide of zinc so formed, and also to improve the conducting power of the water, which, compared with metals, is an exceedingly imperfect conductor. Second in order is the copper, silver, platina, iron, or carbon plate, which is apparently, or at least popularly, considered as the receiver of the voltaic current generated by the chemical action of the oxygen on the zinc. The latter is termed the positive plate, whilst the former, or copper, &c., is called the negative plate of the battery.

Third in order is the conductor, between the two, which, in all ordinary forms of the voltaic battery, is a metallic wire. The current, established at the surface of the zinc, traverses the liquid, and arriving at the negative plate, is thence again conducted to the zinc by the conducting wire. Now all the effects of voltaic electricity, such as light, heat, electro-magnetism, &c., occur between the exterior of the plates of a battery, and generally between the terminals of the wires that proceed from the last two plates of the cell or battery. As already shown in the preceding chapters, it is by the resistance offered to the passage of the current, that a voltaic arrangement affords the phenomena of light and heat. The same may be said of the electro-chemical phenomena; because, as long as a good conductor of a metallic character, sufficient to convey the current, is employed, neither light, heat, nor chemical effects are produced. But in respect to magnetic or electro-magnetic phenomena, the same rule does not hold good. The good conductor, such as a metallic wire, assumes, whilst the current passes, magnetic affections; or, at all events, affects magnetised bodies, as we have already shown in the preceding article on electro-magnetism. Consequently, in all electro-telegraphic arrangements that essentially depend on electro-magnetic phenomena, it is essential that a good conductor should be employed to produce the best possible effects.

This leads us to consider, in the second place, *the means of conveying a voltaic current for the purpose of the electric telegraph.*

Practically, with an exception to be pointed out, metallic conductors can alone be employed for telegraphic purposes; for they, above all others, convey the current most rapidly, and with least loss of the force. The best ordinary metal that can be employed is copper; that is, for the same section or transverse area, copper is the best conductor for all ordinary purposes. Its expense, however, is very great; and early in 1841, we recommended, in a letter to the *Philosophical Magazine* (which was promised to be, but never was, inserted therein), that iron wire should be substituted for copper, using an iron wire, of greater sectional area, to compensate for its inferior conducting power to copper. The relative expense of the two, per pound, is as $1\frac{1}{2}$ to 13; or copper is about eight times as expensive as iron wire. But the greater weight, dependent on the greater sectional area that must be employed of the iron wire to compensate for its inferior conducting power, increases the cost of the latter so as to diminish the ratio between the price of copper and iron wire for telegraphic purposes. Again, common iron or steel wire would soon get corroded in the atmosphere: hence it is now universally "galvanised;" that is, it is covered with a coating of zinc, that protects it for a long time from atmospheric action, and that of moisture. Steel wire is still better than iron wire, because of its elasticity.

The protecting power of the zinc coating becomes, however, seriously impaired by a very singular cause. Near manufacturing towns, such as Glasgow, Manchester, &c., and in the iron districts of this country, where immense quantities of coal are burned daily, one product is sulphuric acid. It has been calculated that Manchester, from its factory chimneys, produces daily several tons of sulphuric acid from the coals consumed in the furnaces. This arises from the fact, that nearly every kind of furnace, steam, or gas coal contains sulphur; and that, during the combustion of such coal, the sulphur becomes oxidised, and is converted into sulphurous and sulphuric acids. The latter speedily attacks the zinc coating of the telegraph wire, if of galvanised iron, and destroys it. A galvanised iron roofing, erected, some years ago, at the Stepney station of the Blackwall Railway, near London, was completely cut through and destroyed by the sulphuric acid and steam of the locomotives passing under it. Consequently, in the neighbourhood of large towns, the wires formed of galvanised iron undergo rapid corrosion. It has been stated that, in some localities, wires originally a quarter of an inch or more in thickness, have been, by such causes, reduced to the size of an ordinary pin. The sulphuric acid, acting on them, forms first a sulphate of zinc, that dissolves off, and then a sulphate of iron, which also dissolves off.

In the early stages of the application of the electric telegraph, the wires were enclosed in an iron tube, as already stated in respect to the

Blackwall Railway, at p. 491, *ante*. At the present day, the metropolis, and many of the large cities and towns of this and other countries, have the telegraph wires still arranged in a similar manner. Each wire being covered with gutta-percha, or other non-conducting material (of which we shall have more to say hereafter), a number of them are enclosed in iron troughs that are fixed a few inches below the roadway, generally at the edge of the foot-pavement. At certain intervals, short, hollow iron posts were fixed, through which the wires were carried at a height of about four feet above the ground; the object of the latter arrangement being that of permitting the testing of a faulty wire; and when its locality was found out, the wires were taken up from the ground, and the defective one repaired. A better plan is now adopted for this purpose. An example of this is found in a system of wires running out of London, northwards by the Holloway Road, through Highgate Archway, up nearly to Finchley. The wires from town are imbedded in troughs beneath the roadway; but as soon as open country is arrived at, they are then suspended on poles, placed at about sixty yards apart—or nearly thirty of such poles are erected per mile—to support the telegraph wires.

Now, however good a telegraph wire may be as a conductor, still, unless it is insulated, the current it is intended to convey would be diverted from the wire by many causes. For example, if the wire were simply nailed to the post, at the first shower of rain the post would become moist; and, consequently, it would, at the same time, become a partial conductor of electricity, taking a part, and in some cases the whole, of the current to the earth—especially when the latter takes the place of a return conductor, as already explained, but which will again require remark.

The term *insulation* is equivalent to non-conduction; but some of our readers may require a popular explanation of what we mean. No sensible person would attempt to take a kettle, full of boiling water, off the fire without wrapping a piece of paper round the handle, to prevent the fingers being burned Yet, if the kettle be removed, and its lower surface be black, after a few seconds the kettle may be placed with the bottom on the hand without the least harm being incurred, although the inside is filled with boiling water. Now, the reason that the paper at the handle, and the charcoal at the base of the kettle, prevent injury to the hand, is simply because they are *both bad conductors of heat;* hence they do not permit of the heat passing from the boiling water to the hand. Again, the handle of a metal teapot does not hurt the fingers, whilst the body of the pot does. But, on inspection, it will be found that the handle of the teapot is separated from it by means of two thin discs of wood or ivory, which prevent the heat of the pot reaching the handle.

Now, the insulators of the telegraph post answer precisely the same purpose. They prevent the passage of the electric current from the wire to the earth; not entirely, it is true, but still sufficiently so as not to cause a great or sufficient loss to impair its efficacy for telegraphic purposes. In this country earthenware is largely, indeed chiefly, used as an insulating material, although glass is occasionally employed. The latter material is much in use in the United States for insulating purposes.

The manner in which the wires are suspended on the post is too familiar to all our readers to require description, as there is scarcely a town of any pretension in the kingdom where telegraphic wires may not be seen.

Of course, as already stated, these insulators are only partially successful in preventing the loss of the current. In wet weather, when the stoneware, glass, and the wooden poles all become moist or running with water, and also in damp fogs, it is necessary to employ a much greater amount of battery power to produce the signals at a distant station. Moisture is to a telegraph wire what a leak is to a pipe or vessel holding liquid. We well know that to fill a leaky vessel requires a greater supply-stream than is needed for one that is sound; and, similarly, any cause that impairs the efficiency of an insulator or non-conductor, in respect to a telegraph wire, produces an analogous result.

When we enter on the description of submarine cables we shall have to deal fully with the insulating powers of the materials—such as india-rubber, gutta-percha, etc.—employed therein. Of course, although such an external protection to a wire suspended in the air would, or should, completely insulate it, still, as it is not absolutely necessary, and would be extremely costly, such a plan is never adopted on land lines, except where the lines are conducted through tunnels; and not always in such cases, unless the tunnel be a wet one through the dripping of water. As a rule, however, in such cases, the wires covered with gutta-percha are enclosed in a tube, because the height and shape of the tunnel would not permit a great number of wires to be hung on its sides, most of our long railways having numerous wires as a part of the telegraphic system.

It has been already remarked, and abundantly illustrated, that the greater the length of the wire employed for the transmission of messages by the electric telegraph, the greater is the resistance to the passage of the current; hence, in practice, it would be more economical to employ a series of short wires in telegraphing between distant stations. Thus, supposing a message was sent from London to Glasgow, there might be a break at Rugby, Preston, and Carlisle, each station averaging about eighty miles apart of distance. But, of course, such breaks would greatly lengthen the time required for the transmission of the message; and not only so, the clerks needed to make such repetitions of a message would have a vast deal more work thrown on their hands, and this would, of course, become a source of additional expense. Consequently, it is better in the end that each large city should have its independent wire, so far as it can be practically made to pay. Hence

the number of wires that are required for the ordinary telegraph system, as may be noticed in a journey northwards from London.

One of the most important discoveries that has been made in telegraphy, was that of finding out the fact that the earth may be made a "wire" for a return current. This discovery has already been explained and illustrated at a previous page; but the following remarks, illustrative of the subject and its history, will be read with interest:—

"In the year 1838, a great discovery was made, which favourably influenced the electric telegraph. Until then a return wire was supposed to be necessary for the purpose of completing the circuit at the voltaic source. Steinheil discovered that this was altogether an error, and that the earth might be substituted as the return conductor. To this most valuable discovery the name of the 'earth circuit' has been given, and its nature may be best illustrated by the experiment which led to it. Experimenting on the railway at Munich, Steinheil had made a circuit of which the two iron trams were part; a connecting wire completing it. The charge was passed down one tram, crossed the interval between the two upon the connecting wire, and returned upon the other tram. The wire being removed, it was supposed that the circuit was broken; but it was found that the current passed through the wire, and returned by the shortest route to the battery. By virtue of this most important experiment, the return wire is dispensed with in the following manner:—One of the wires of the battery is carried down to the earth, and there attached to a large iron or copper plate, or to the gas-pipes, if near; and the same being done with the wire proceeding from the other pole, and extending to the receiving station, the circuit is completed through the earth by the line of best conducting power between the plates. Not only has this discovery enabled telegraphists to dispense with the return wire to the voltaic source, and thus effected an important economy of material, but it presents the possibility of reducing the resistance of the current below the amount it would experience in passing through the wire. From the latter circumstance an economy of battery power results."

There is nothing in electrical science so surprising as this fact—that a return current may be established through miles of earth. In an economical point of view, it may be considered as the essential condition of the success of a telegraphic system. In our laboratories we always employ two wires for each current; and if the same plan were needful in telegraphy, with a small deduction, the companies now existing must have raised double their present capital to carry out their business, had not the earth circuit been discovered as available. In his treatise on the *Electric Telegraph*, Dr. Lardner remarks:—

"Of all the miracles of science, surely this is the most marvellous. A stream of the electric fluid has its source in the cellars of the Central Electric Telegraphic Office, Lothbury, London. It flows under the streets of the great metropolis; and, passing on wires suspended over a zigzag series of railways, reaches Edinburgh, where it dips into the earth, and diffuses itself upon the buried plate. From that it takes its flight through the crust of the earth, and finds its own way back to the cellars at Lothbury, London.

"Instead of burying plates of metal, it would be sufficient to connect the wires at each end with the gas and water-pipes of each city, which, being conductors, would equally convey the fluid to the earth; and, in this case, every telegraphic despatch which flies to Edinburgh along the wires that border the railways, would fly back, rushing to the gas-pipes which illuminate Edinburgh; from thence to the crust of the earth, to the gas-pipes which illuminate London; and from thence home to the batteries, in the cellars of Lothbury." Our readers who have gas laid on in their houses, may still further extend the ideas expressed by Dr. Lardner; for, in every city, town, or village that an electric telegraph has been established, each house having within it a gas-pipe must of necessity become an electric telegraphic station, through which, at perhaps almost every instant, a message of vital importance is being passed, although unobserved by the occupants. Such facts—for facts they are—exceed the wildest dreams of man's most excited imagination.

In the arrangement of the wires of the telegraph, as seen by the side of railway stations, a careful observer will notice that, at certain places, one of the wires ceases to have contact with its apparent fellow; and here it is that a kind of special station is established. For example, a line of wire is continuous on the London and North-Western line, as far as Rugby, or on the Great Northern Railway at Peterborough. The wire is stopped electrically in its progress at such stations; or, in other words, the message sent from London is not indicated at any station beyond those named. The message is, accordingly, delivered at that station only; but, of course, by means of another conducting wire, may be communicated to any other station north of those named. This plan is only adopted in certain cases. For example, the railway-message traffic between London, Rugby, Crewe, or Wolverton, must necessarily be of the highest importance in respect to the management of the railway—the company having extensive works for the supply of locomotive power at the Camden (London), Wolverton, and Crewe stations, whilst Rugby is a central station for a number of diverging railways. Now, under such circumstances, it is imperative that immediate and constant communication be kept up. An accident may happen that may require special despatch of a locomotive, that cannot be available except at the stations just named. Again, at all of them, or, at least, two of them, an abundant supply of human aid can be instantly obtained in case of accidental occurrences. Hence the necessity of direct communication with such stations, that is effected by the means just pointed out.

We may next notice some of the obstacles, other than those of conduction, occurring through bad or imperfect insulation. Such arise from several causes, as atmospheric electricity, earth currents, induction of a secondary current in the conductor, resistance, &c., &c.; omitting, for the present, any consideration of the peculiar circumstances that govern the action of submarine cables, or affect their efficiency.

In the first place, the wires suspended on poles in the open air, are liable to many accidents that impair their conducting power, apart from questions of moisture and insulation in respect to the poles that sustain them. At a previous page, an incident has been related of an amusing kind, that illustrates the numerous accidents that may thus arise: it was, that a metallic-framed window being opened to ventilate a cottage for an hour or two daily, the frame got into contact with two of the suspended wires, and so completely arrested the passage of the current; in fact, it was completely cut off at that point. It is by no means an uncommon occurrence, again, to see the string of a boy's kite crossing a lot of telegraph wires. So long as the string is dry, of course no harm results; but as soon as it becomes moistened with water from fog, rain, or dew, then a partial, although imperfect, conduction occurs between each wire, and, consequently, the conducting power of each so connected is lessened.

Here we may notice a very common but popular error—that birds flying against telegraph wires suspended in the air, are at times killed by a shock from the electric current. In the first place, such is quite impossible, from the fact that not the least part of the current could be directed into the body of the bird, simply because the animal is not in the circuit; and, secondly, if it were, the amount of electricity passing would be quite insufficient, in all ordinary cases, to cause death to birds. Their rapidity of flight is quite sufficient to account for their death, owing to the mechanical shock they sustain on getting into contact with the wires.

The free electricity of the atmosphere is a source of frequent annoyance to the telegraphist. Nearly always a certain amount of electricity can be detected by an electrometer; but in the case of the thunder-storm, or during dense fogs, the amount becomes not only annoying, but even dangerous. Mr. Crosse, of Bromfield, near Taunton, several years ago, erected a large number of iron rods in a field, perpendicularly, attaching them to poles, and the lower end of each rod was connected to the rest by stout metallic wires. The latter were all connected together, and terminated in a thick conductor, that was fixed in what he termed an electrical room, but what might have been aptly termed a thunder-house. On the approach of a thunder-storm, or a dense fog, the free electricity was collected by these iron rods, and, arriving at the terminal conductor, rushed with torrents of fire and a fearful noise, to a conductor arranged at a small distance from the one described, so as to carry off the electricity to the earth. All the phenomena of a heavy thunder-storm were thus concentrated into a space of a few inches, and the effects were as magnificent as they were appalling.

Now, the poles on which the telegraphic wires are suspended, and the wires, produce exactly such an apparatus as that just described; but instead of extending over only an area of an acre or two, they run through scores, and, perhaps, hundreds of miles of country. Under such circumstances, it is a matter of no surprise, that at times the suspended wires become conductors of the enormous amount of free electricity in the atmosphere. Resulting from this, the operators at telegraph stations have been frequently knocked down, and seriously injured by lightning. But if they have at times escaped, the instruments have suffered, especially if the needle telegraph (to be presently described) were employed. We may here briefly remark that the needle instrument consists of a magnetic needle suspended within a coil of fine wire, in such a manner as that it may oscillate right and left, according as a current of electricity passes from the battery over it. In case of powerful storms, the free electricity in the atmosphere has had frequently the effect of inverting, or even destroying the magnetism of the needles, and rendering them useless. Many plans have been suggested to prevent such results. At first lightning-conductors were affixed to the posts; but more ingenious arrangements were also had recourse to. Of these, Dr. Lardner remarks:—

"Mr. Walker, of the South-Eastern Company, and M. Breguet, of Paris, each invented an instrument for the better protection of telegraphic stations from atmospheric electric discharges. Both these contrivances have been found, in practice, to be efficacious; and though differing altogether in form, they are similar in principle. In both, a much finer wire than any which lies in the regular route of the current is interposed between the line wire and the station, so that an intense and dangerous atmospheric current must first pass this fine wire before reaching the station. Now it is the property of such a current to raise the temperature of the conductor over which it passes to a higher and higher point, in proportion to the resistance which such conductor offers to its passage. But the resistance offered by the wire is greater in the same proportion as its section is smaller. The safety wire interposed in these contrivances is, therefore, of such thinness that it must be fused by a current of dangerous intensity. The wire being thus destroyed, all electric communication with the station is cut off, and the extent of the inconvenience is the temporary suspension of the business of the line until the breach has been repaired.

"Expedients are used, on the American lines, to divert the atmospheric electricity from the wires, consisting merely of a number of fine points projecting from a piece of metal connected with the earth by a rod of metal. These points are presented to a metal plate, or other surface, attached to the line wire at the place where it enters the station. It is found that these points attract the atmospheric electricity,

which passes to the ground by the conductor connected with them, but do not attract the electricity of the battery current."

The reason of this is, that the battery current has far too little intensity to leap through the smallest space between two good conductors not in contact, whilst the atmospheric electricity can easily perform that feat.

Earth currents—that must here be only partially noticed, as they will again become the subject of discussion in connection with submarine cables—are a frequent, not to say constant, source of annoyance to the telegraphist. We have known a telegraphic system (between Edinburgh and Glasgow) become completely suspended from action through such causes. The production of these currents has been variously accounted for, either as being created in the crust of the earth, or by the influence of temperature on the earth and in the air. Many years ago, Mr. Fox proved the existence of such currents in mines and localities where the electricity of the earth below the surface can be tested. A very feasible, and, indeed, most probable cause of their production may be thus stated. As the sun rises it heats that portion of the earth where its rays first appear; whilst, at a greater distance west, the earth is cold. Now, according to the teachings of thermo-electricity, we know that if two bars, one of antimony and another of bismuth, be soldered together so as to form a rectangle, and if one corner of this be heated, whilst the other is kept as cool as possible, a current of electricity will be generated from the heated to the cool portion, that will be quite sufficient to deflect a magnetic needle. Of course, in nature, such results must also take place under the circumstances above named; and it is well known, from that cause, currents of electricity are constantly passing from east to west. The daily variation of the magnetic needle seems to be produced from such causes, but it has been suggested that the magnetic influence of the sun should be taken into account. The aurora borealis also affects the needle.

Another, and, formerly, a most insuperable obstacle, was that of a new current being induced in the wire carrying that of a voltaic current. This was at one time considered so serious a difficulty, that long submarine cables were predicted as necessarily to become failures. In some early experiments that we conducted with long lengths of fine wire (900 miles), the electricity, instead of producing an instantaneous effect at the further extremity from the battery, actually dribbled out—if we may so say—requiring an appreciable length of time to effect the full result of an only instantaneous current from a battery. It seemed, indeed, that instead of electricity flashing through a conductor at the rate of 200,000 miles or more per second, that its velocity was barely 3,000 or 4,000 miles. But subsequent inquiry showed that the real cause of this phenomenon was, not a slow rate of the travelling of the current, but that induction of a new current took place, which not only retarded the progress of the primary current, but, to an extent, neutralised it. In long cables, such as the Atlantic, the cable is really a Leyden jar of enormous length, but of small diameter. The wire inside the core becomes equivalent to the inside coating of a Leyden jar; the gutta-percha, or other insulators, surrounding it, takes the place of the glass or dielectric; whilst the exterior of the cable may be considered as the equivalent of the exterior of the Leyden jar. Now, when a current from the voltaic battery is sent through such a length of insulated wire, the latter becomes charged just like a Leyden jar, and retains the charge for an appreciable length of time. It will be, hereafter, our duty to investigate this matter fully; but some idea may be obtained of the reduction of speed that occurs in the transmission of signals by such causes, from the results obtained by Mr. Clark, who experimented upon a cable coiled in the East India Docks, seventy-seven miles in length, containing six wires, and the property of the Electric and International Telegraph Company. These experiments were fully detailed in his admirable report to the joint committee of the Board of Trade, in 1861. His observations showed the following results:—

Length of Cable in Miles.	Time of Transmission in Seconds of Time.
77	·025
154	·045
231	·080
308	·115
385	·140
462	·160

These experiments, however, are not to be implicitly relied on, because the instruments used by Mr. Clark were hardly suitable for the purpose. At the same time, they serve to show that, independent of the resistance due to length, the induced current has a retarding effect.

When the wires are suspended over-head, of course any break can at once be detected, and remedied; but if sunk below the ground, such defects are with difficulty discovered, except by testing. For this purpose, short posts, as a hollow cylinder, or upright box of iron, are erected at certain intervals. Through these the wires, covered with gutta-percha, are conveyed. If a fault be suspected in any one, or known to exist, the wire that is defective is cut at a point as near as possibly may be guessed to be faulty; a current is then passed from it through a galvanometer, and the deflection is noticed. By subsequent trials, observing how much less the needle of the galvanometer is deflected less than it should be with the current employed, the spot of defective insulation may be arrived at. The method of detecting such faults, however, especially in case of submarine cables, will be more fully investigated hereafter. The point of fault in wires laid underground may be thus easily discovered by testing the wires enclosed in each of the upright posts already named, by means of a portable battery.

In consequence of the number of wires that are often made into a bundle, and laid in a trough beneath the ground, it is essential that

the wire should be of as small diameter as possible; because, to prevent metallic contact, each has to be coated with gutta-percha, or with non-conducting material; and, with this covering, a wire of No. 16 copper gauge attains a thickness of at least $\frac{3}{8}$ths of an inch in most cases. Copper wire is employed, therefore, as its superior conducting power above that of iron wire, permits of its being employed of a much smaller diameter than iron wire. It is essential that it should be as pure as possible; because, if not of the best quality, its conducting power becomes much diminished. There, in fact, occurs a difference of no less than 50 per cent. between the best and worst wires in that respect. Again, if it be not soft, it may be broken with but little violence, especially if it have been long employed to conduct an intense current of electricity. We have had copper conducting wires, an eighth of an inch in thickness, become so brittle after having been used with a battery of fifty cells of Grove's or the carbon battery, that it might be broken with the fingers.

The excellence, softness, tenacity, and, consequently, the purity of the iron wires suspended on posts in the air, are all matters of great importance. Of course, the strain to which such wires are constantly subjected is very great. The force of the wind is at times sufficient to blow over both wires and poles. Some of the wires belonging to the London District Telegraph Company have suddenly broken, suspended as they are, from house to house at times, through great distances; and in more than one instance fatal accidents have resulted. Indeed, some years ago, during a very violent storm that visited the metropolis, nearly the whole system of those over-head wires was destroyed. The manufacture of iron telegraph wire, and its galvanisation, have become a new business. One of the most improved methods, producing wire of the requisite quality for telegraphic purposes, is thus described in *Engineering:—*

"Messrs. Johnson and Nephew, of Manchester, the well-known wire-makers, have for some time had in successful operation what they term a 'continuous mill' for rolling wire, invented and patented by Mr. George Bedson, the manager of their works. The principal object aimed at in his invention, is the production of a continuous piece of wire, without break or welds, of much greater length than can be obtained in the wire-mills now generally in use. The mill consists of a long series of rollers placed in pairs alternately horizontally and vertically, each pair of rollers having one groove, through which the wire passes, and is delivered to the next pair of rollers, reduced in section, and extended proportionately in length. The gearing of the rollers is arranged so as to give a higher speed to each successive pair of rollers, in order to pass the increasing length of wire through as quickly as it is produced. The relative speeds of the different rollers, as well as the relative sizes of their grooves, have been arrived at, after a great number of experiments, and they form the principal element of success in working. The mill is placed at the mouth of a Siemens' gas-furnace, in which a bar or billet of iron, up to eighteen feet long, and weighing about eighty pounds, is introduced from the opposite side. The bar, when properly heated, is drawn into the mill by its front end, and is slowly drawn out of the furnace by the mill itself as the process of rolling proceeds. The present arrangement of mill rolls the wire down to about $\frac{1}{4}$ in. diameter, and a continuous coil of such wire is shown at these works, weighing 102 lbs., and made from one bloom at one single operation. In the course of the operation, there is, of course, one part of the billet within the furnace, whilst another part is being coiled up at the other end of the mill in the form of wire. The speed of rolling is very considerable, and the capability of production of the one mill now at work in Messrs. Johnson's establishment, is stated to be 100 tons of $\frac{1}{4}$-in. wire per week. Mr. Bedson is now making arrangements for rolling still finer wire than the above-named size, so as to have still less work to be performed by drawing the same down to the dimensions required for telegraphic purposes.

"The operation of galvanising is carried out on the modern principle of passing the wire at a dull red heat through hydrochloric acid, and, after that, immediately running it through a bath of zinc. The process is performed by a kind of self-acting apparatus, having a series of drums, each of which coils one wire upon its circumference while revolving by steam-power. These wires are uncoiled from other drums placed at the opposite end of a furnace and of the troughs containing the acid and zinc, through all of which the wire is drawn in succession by the machine at an uniform speed. There are seven machines of this kind at the works in question; and their power of production is estimated at about 250 tons of wire per week. Some of the best wire, after being galvanised, is straightened and stretched by another simple apparatus. This consists of two drums worked by steam-power, and geared so as to give the winding-drum a circumferential speed exceeding that of the other drum by 2 per cent. The wire, being unwound from the latter, must, therefore, stretch to the extent of 2 per cent. in order to make up for the difference in speed. The straightening of the wire is effected by passing it between a series of pins set in a straight line, which bend the wire alternately in opposite directions, and thereby straighten it. The tension which this last process puts upon the wire can be ascertained by direct measurement; and this operation serves, therefore, at the same time, for a test of the strength and quality of the wire, each part of its entire length being in succession submitted to this practically uniform strain.

"The best iron is made from rolled bars, cut into short lengths, and piled up longitudinally. These are hammered and rolled out into bloom ready for the continuous mill. There are twenty puddling furnaces at Messrs. Johnson and Nephew's works, the produce of which is partly

rolled into wire of inferior quality direct from the puddled bloom, and partly made into scrap for the best class of wire. The average consumption of fuel is three tons of coal per ton of wire produced. The manufacture of telegraph wire has now become a distinct business.

It is remarkable how few instances of wilful damage occur in regard to telegraphic wires suspended in the air, except in certain cases that have happened in Ireland, induced by political, or rather rebellious, causes. On this Dr. Lardner remarks—"It has been contended, in Europe, that the wires would not be safe unless placed within the railway fences. The reply to this is, that they are found to be safe in the United States, where there is a much less efficient police, even in the neighbourhood of towns, and in most places no police at all. It may be observed, that the same apprehensions of the destructive propensities of the people have been advanced upon first proposing most of the great improvements which have signalised the present age. Thus, when railways were projected, it was objected that mischievous individuals would be continually tearing up the rails, and throwing obstructions on the road, which would render travelling so dangerous that the system would become impracticable.

"When gas-lighting was proposed, it was objected that evil-disposed persons would be constantly cutting or breaking the pipes, and thus throwing whole towns into darkness."—These remarks were penned by Dr. Lardner some years ago; and up to the present day, except in very rare cases, telegraph wires, gas-pipes, and railways, have enjoyed a singular immunity from wilful damage. Even in comparatively uncivilised countries, such as India, and the East generally, it rarely happens that intentional damage arises; although, from the number of wild beasts in those countries, the European suspension-pole would be of no use, as a clumsy or mischievously disposed elephant would soon make short work of such a system. Consequently, in place of the pole a pillar of masonry is erected to carry the wires, and, from its strength, defies the attack of the wild beast, as also of terrific storms.

Having thus given a general account of the sources of electricity, and the mode of conveying it from station to station on land, we next turn to the consideration of—

Submarine Cables.

The success of telegraphic enterprise on land soon led to its extension beneath the sea. According to Dr. Lardner, and other authorities, "The earliest attempt to transmit a voltaic current under water for telegraphic purposes, is attributed to Dr. (after Sir W.) O'Shaughnessy, who is so well known for his successful exertions to establish the electric telegraph in India. He succeeded, in 1839, in depositing an insulated conducting wire, attached to a chain cable, in the river Hooghly, by which the electric current was transmitted from one bank of that river to the other.

"The first important project of this kind which was executed in Europe, was the connection of the coasts of England and France by the submarine cable, deposited in the bed of the channel between Dover and Calais. A concession being obtained from the French government on certain conditions, a single conducting wire, invested with a thick coating of gutta-percha, was sunk by means of leaden weights across the channel, and the extremities being put into connection with telegraphic instruments, messages were transmitted from coast to coast. One of the conditions of the French concession being, that this should be effected before September, 1850, this object was attained, but nothing more; for the action of the waves near the shore constantly rubbing the rope against the rocky bottom, soon wore off the insulating envelope, and rendered the cable useless.

"It is right to state, that the projectors themselves did not expect from this first trial permanent success, and regarded it merely as the experimental test of the practicability of the enterprise. It was, therefore, immediately resolved to resort to means for the effectual protection of the conducting wires from the effects of all the vicissitudes to which they would be exposed. With this view, Messrs. Newall and Co., the eminent wire-rope-makers of Gateshead, were charged with the difficult and unprecedented task of discovering expedients by which a cable of gutta-percha containing the conducting wires could be invested with an armour of iron, at the same time so strong as to resist the action of the forces to which it would be exposed, and yet not too ponderous nor too rigid to allow of being deposited in the bed of the channel. The result was the invention of the form of submarine cable which has since been successfully adopted on the various lines of international electric communication."

The amount of difficulty that has to be overcome in properly constructing a submarine cable, can only be estimated by those who are practically acquainted with the subject; and even with them fresh difficulties are constantly arising from unforeseen circumstances that frequently occur. Bad insulation, from defective manufacture, and a variety of other errors, has continuously caused the failure of submarine cables; an instance of which is illustrated in the first attempts made to lay a cable from Ireland to America, that must be familiar to most of our readers, and of which we shall have to say more hereafter.

A submarine cable essentially consists of three parts. First, the internal wire, or wires, that are intended to convey the electrical current; secondly, of the insulating medium, or media, which prevents the transmission of the current from the wire to the sea; and, lastly, of the external protecting coating, which is generally formed of twisted iron or steel wires, that surround the gutta-percha, india-rubber, or other material enclosing the conducting wires.

Now it will be obvious that the strain which hangs on an electric cable, whilst being sunk in

the water, will depend on the length that is dependent from the stern of the ship. In crossing the English Channel that depth is comparatively trifling, the sounding not greatly exceeding twenty or thirty fathoms ; but in the Atlantic, the Mediterranean, and other deep spaces of water, the strain on the cable is enormous ; and, no matter what strength has been imparted to it, risk of fracture constantly occurs. Another point of importance is, that, if a cable be very long, its weight becomes so enormous as to require vessels of great tonnage ; hence it is more than likely that the Atlantic telegraph would never have been successfully laid had it not been that a *Great Eastern* steam-vessel had been available ; for it must be remembered that, from one cause or other, all attempts preceding that of 1866 were failures.

The Dover and Calais submarine cable was the first laid for practical purposes in Europe. It had four copper conducting wires, each surrounded by gutta-percha, as a first insulating medium. These were packed in the centre of the cable, and were surrounded with spun yarn. Over this mass were twisted, &c., galvanised iron wires, to form a protecting external surface, to prevent injury by attrition against rocks ; breakage by its being raised by anchors of vessels—a circumstance of constant risk in the channel ; and to prevent various other risks of accidents that will at once suggest themselves to our readers. The length of the cable was twenty-five miles, and electric communication was established successfully through it on the 17th of October, 1851. Its total cost was about £9,000 ; but, including stations, etc., Dr. Lardner puts the cost at £15,000.

The same authority states, that the next submarine cable laid down was that which connected Holyhead, on the Welsh coast, with Ireland, at Howth. While several companies, which had been formed for the purpose, were occupied in raising the necessary capital for the project, they were surprised by the announcement that it was already on the point of being realised by Messrs. Newall and Co., of Newcastle, on their own account.

Here we must break off, for the purpose of stating that much of the success of the submarine telegraph of the last eighteen or twenty years, has been due, so far as material is concerned, to Messrs. Newall and Co., in respect to wire covering, and the London Gutta-Percha Company, in insulating material. At the present day, when the manufacture of submarine cables has ceased to be a wonder, the early obligations which the art or business was under to those firms is forgotten. It is, however, quite certain, that whatever improvements have been introduced (and most successful they have been), we are materially and primarily indebted to the firms just named for early enterprise in supplying submarine telegraphic requirements.

The Howth cable was jointly made by Messrs. Newall and Co., of Newcastle, and the Gutta-Percha Company, of London ; its external wire being supplied by the former firm. It only possessed one interior conducting copper wire, and was seventy miles long. Its weight was but one ton per mile ; whilst that of the Dover and Calais line weighed seven tons per mile. But in the latter there were not only four conducting wires, but, owing to its great diameter, the external coating of iron wire, of course, weighed much heavier than the Holyhead and Howth cable. The following cuts show a section of a submarine cable, and its general longitudinal

Fig. 267.

appearance. At the present time it is universally the case in deep-sea cables, that the shore ends are made much stouter than the intermediate portion ; because, whilst the latter is scarcely disturbed in deep seas, the ends that reach the coast are liable to a variety of accidents of all kinds, that will naturally suggest themselves to the minds of our readers.

Before passing on to describe some of the particular features of submarine cables that have been laid, we may advantageously give the unpractised reader some idea of how a submarine cable is, in the main, constructed. In the annexed engraving we have taken that for illustration which was first laid between Dover and Calais.

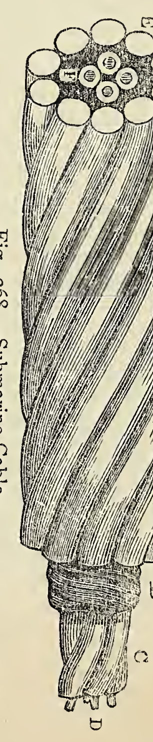


Fig. 268.—Submarine Cable.

First, we observe, that the outer portion of the cable consists of a coating of thick iron wires. These are twisted on by means of powerful machinery ; and when this is well performed, they afford a sufficient protection to all that they enclose within their folds. The size of these wires varies according to the strength required, and the circumstances in which the cable may be placed. In shallow water, the external coat requires to be much stronger than in deep sea, because of the pebbles and broken rock against which it may rub. After a cable has laid for some time beneath the surface of sea-water, it acquires a curious coating, which has the power of affording it additional protection. This consists

of the shells of mollusca which attach themselves to it. It gradually increases, and sand, &c., soon become completely attached to the wires, forming an external surface of great solidity and strength. This, which, at first sight, seems to be a source of danger to a cable, becomes one of its most valuable protectors; and, instead of decreasing and wearing away, it accumulates continually. The dangers, then, of injury from such sources, peculiar to immersion in sea-water, occur only for some time after the cable has been laid, and decrease as the coating we have described accumulates. We observe, next to the external metallic coating, a covering of hemp, B, which is wound round the next coating of, C, gutta-percha, enclosing each wire, D. The object of this hempen coat is to allow of play between the covering of the conducting wires and that which forms the outside of the cable. The hemp is saturated with a mixture of grease and pitch, which, to some extent, tends to protect the gutta-percha from the attacks of marine animals; for any greasy substance is always avoided by them. Should the cable be accidentally bent at too acute an angle, the coat, by its elasticity, prevents the snapping of the fine internal wires.

This illustration only refers to some cables that have been laid; for almost every variety of insulating material has either been proposed or adopted. For a long while gutta-percha alone was employed. India-rubber was then considered as a better insulator, and, of course, many propositions were made for its universal adoption. But, apart from the question of expense, many difficulties arise in the use of india-rubber for long cables. The pliability, and comparatively easy working of gutta-percha, recommend it for almost every purpose; but its insulating powers are inferior, in many respects, to other substances.

At the British Association meeting in 1865, at Birmingham, a substance, now familiarly known under the name of Parkesine (from the name of its inventor, Mr. Parkes, of Brighton), attracted great attention on account of its general applicability for all purposes in which india-rubber and gutta-percha may be employed, but especially as a substitute for them as an insulator for submarine cables. We are not aware that it has ever been employed to any extent for such purposes; but many of our practical readers may find some interest in perusing the following account of its general and electrical properties, as stated at the meeting just mentioned. It was there remarked, that "the difficulty of procuring a pure and homogeneous article has, there are reasons to believe, resulted in the total failure of some thousands of miles of submarine cables and underground wires. This, however, has to a great extent been overcome by the adoption of greater care and improved machinery, especially with regard to gutta-percha; but, owing to the inferior quality, and the adulterated state of the raw blocks imported, the expense of manufacture has been greatly increased. Parkesine is placed upon the wire by being forced through a die in successive coatings with the greatest facility, which renders it far less liable to flaws, when laid over wires, than india-rubber, &c. Extensive experiments are now in progress, under the direction of Mr. Owen Rowland (electrician to the late joint committee of the Board of Trade and the Atlantic Telegraph Company, appointed to inquire into the construction of submarine telegraph cables, &c.), with a view of ascertaining, to the fullest extent, the electrical properties and applicability of the material for the above important purposes. The result of those experiments becomes daily more satisfactory, and leaves no reason whatever to doubt that, on the completion of the necessary machinery, a most excellent and efficient insulator will be produced, possessing all the requirements of insulation. In its hard and solid form, by virtue of its high insulating and non-oxidising properties, it is peculiarly well adapted for electrical instruments, terminal boards, testing-boxes, batteries, insulators for poles, and many other philosophical purposes; and the advantages to be derived from the employment of a material which remains free from oxidation under all conditions, will be duly appreciated by electricians and experimentalists in their daily operations and investigations. It is also, as a substance, exceedingly agreeable to the touch, and susceptible of the highest polish; can be turned in the lathe, and cut with screws; as well as exquisite ornamentations, either by the graver, moulding, or colouring. Its tensile strength is considerably above that of either gutta-percha or india-rubber, or any other insulating material. Joints can be made with the greatest facility and perfection. It is not affected even by acids; and sea-water, in which it has been immersed for a period of four years, has not in the least deteriorated its qualities. In dry heat, as high as 212 degrees, it remains electrically unimpaired, and not softened at even a higher temperature. Results of experiments made at Hackney Wick on August 29th, 1865, on the loss of insulation, on lengths of variously coated copper wires, &c.; instrument employed, Peltier electrometer; full tension, 40; temperature, 61 degrees Fah.:—Parkesine, 5 in 1′ 45″; plain gutta-percha, 5 in 0′ 37″; gutta-percha and Chatterton's compound, 5 in 1′ 8″; plain gutta-percha covered with Parkesine, 5 in 1′ 4″; india-rubber (masticated), 5 in 1′ 15″; india-rubber (virgin), 5 in 0′ 30″; ebonite disc, 5 in 2′ 10″; Parkesine disc, 5 in 2′ 35″."

At the same meeting of the association—referring to the previous failure that had occurred in the year 1865, in attempting to lay successfully the Atlantic cable, but which was recovered in 1866-'7, after the cable of 1866 was in excellent working order (both of which will presently receive our careful attention)—Sir William Fairbairn read a paper on some of the causes of the failure of deep-sea cables, and experiments on the permanency of their insulators. The paper (which was very lengthy) commenced by referring to the failure of the Atlantic telegraph cable in 1865, and to the experiments which were made previously to the laying of the cable; also remarking that failures

were not uncommon, and that out of 14,000 miles of cable laid, three-fourths had been failures. Going on to refer to the "conditions of cables," Sir William said there were two things in marine telegraphy which required special attention—the manufacture of the cable, and its submergence in deep water. These conditions were supposed to have been attended to in the late cable, and every possible care was taken, while the *Great Eastern* was properly fitted up in every way for paying out the cable. The tendency of the cable was always to run into loops; and tension to the amount of one-half its ultimate power would injure the insulation. With reference to the recovery of the lost cable, he said the *Great Eastern* must proceed at a slow speed, and that with one end loose, otherwise he would despair of raising it from a depth of 2,100 fathoms. If the grapnel hooked the cable at a few miles distance from the fracture, if it was to be raised $2\frac{1}{4}$ miles, the weight to be raised would be equal to $4\frac{3}{4}$ tons; and to this dead weight would have to be added the friction of the two sides of the triangle, which would be made by the grapnel and the depending cable. What might be the additional strain in consequence of the speed it was not necessary to calculate, as at two miles per hour it would be close upon breakage of the cable. Assuming, however, that the whole strain was equal to six tons, and as it requires a strain of $7\frac{3}{4}$ tons to break the cable, there was only $1\frac{3}{4}$ tons in reserve to carry the bight of the rope to the surface of the water. This was assuming that the cable had been paid out with sufficient slack; but the fact was, that the excess of cable paid out over the distance run was $12\frac{1}{2}$ per cent. of slack, which would be equivalent to dragging some miles of cable through the mud or ooze. Therefore, it would appear fruitless to attempt to raise the cable, unless means were adopted to cut the cable at a given point on the American side, and haul in by a second grapnel, which would hold fast until the cable was cut. These appear to be the remedies with which to meet the difficulties connected with the raising of the cable; and he had very great doubts of its success. The success of submarine cables depended upon such a variety of conditions, that the wonder was they had succeeded so well. In the manufacture of marine cables there was no difficulty in the matter of the copper wire, but great care was necessary with the insulation, and attention to the question of the degree of permeability under great pressure. Generally, the various metals that have been tried stand in the following order of permeability, the first absorbing least, and the last most, water:—Chatterton's compound, gutta-percha, masticated india-rubber, vulcanised india-rubber, carbonised india-rubber, Wray's compound, unmasticated bottle india-rubber. Experiments on insulation are less complete than those on absorption, and had been prosecuted under greater difficulties, and with less variety of conditions. So far as they went, however, Wray's compound retained the charge longer than any other. Gutta-percha is less absorbent, and india-rubber most. The order of merit in the matter of absorption stands as follows:—Vulcanised india-rubber, Chatterton's compound, gutta-percha, masticated india-rubber, Wray's compound, carbonised india-rubber, unmasticated india-rubber. Experiments made as to the effects of temperature on the absorption of water by insulators, at a pressure of 20,000 lbs. to the square inch, with eight square inches area, and one-eighth in thickness, showed that gutta-percha absorbed 0·004 grains at 45° temperature; india-rubber, 0·177 grains at a lower temperature; and 0·45 grains at 75°, or two and a-half times as much as Wray's compound. The various experiments made, however, while showing the relative permeability of different insulators, were insufficient to solve the main question—that of the most perfect insulation, or the ultimate condition of the material surrounding the insulator or conducting wires of the cable.

In the preceding summary of Sir William Fairbairn's remarks, he generally touches on the cause of failure of submarine telegraphy; but, although the early portion of his remarks are of the greatest value, as we shall hereafter see, it is chiefly to the relative insulating powers of the different compounds named at the end of his observations, that we, for the present, draw attention.

But in all matters of human knowledge, progress must necessarily be a law; and, accordingly, in the following year (1866), an improvement was suggested by Mr. Hooper, who, by a peculiar process, greatly adds to the insulating properties of india-rubber, and especially in respect to its durability. At the meeting of the British Association for that year, Mr. Hooper read a paper on the peculiar advantages of his material in an electrical and a mechanical point of view. He confirmed the durability of his wire by references to experiments made by Sir Charles Bright on a length, which, after being exposed to most trying conditions for three years, had increased about 33 per cent. in insulation. He supplied to Captain Mallock, for further experiments in India, a length made in 1862, which had been in use on his factory for two years, exposed to the sun and weather. This length, notwithstanding its early date of manufacture, is at 75° Fah., three times better than the very best gutta-percha. Mr. Latimer Clark, the government engineer, had considered it unnecessary to ship Mr. Hooper's cables in water-tanks; and the Ceylon cable, then *en route*, was coiled dry. Such practice would be highly dangerous with gutta-percha cables. Diagrams representing the effects of pressure and immersion were shown; from which it was seen that pressure improves the insulation of his wire, in the same way as is observed with gutta-percha. The result of carefully-conducted experiments, extending over three years, proves that the absorption of water is so small that the most refined electrical tests failed to discover it. Its low induction offers the following points of commercial interest:—First, it would be possible to construct an Atlantic core, giving precisely the same speed as the present gutta-percha

cable, for £75,000 less; secondly, by using similar proportions, the yearly income arising from an Atlantic cable may be increased about £200,000; and that for every increase made in the rate of transmission through the present gutta-percha cable, a corresponding increase can be attained with Mr. Hooper's core without any further cost. Thus, if the Atlantic Company adopted any means which, with a gutta-percha cable, could double the present rate of sending messages, Mr. Hooper's cable, with similar appliances, would produce an increase of £400,000 per annum. Mr. Varley has shown, that a cable made of gutta-percha, if only just able to pay the working expenses, would, if replaced with Mr. Hooper's core, pay a dividend equal to 37 per cent. of the working expenses; and points to the advantages which would arise from its adoption for the Red Sea, should this line of telegraph be again attempted.

We have now before us a report of some electrical tests applied to various submerged submarine cables; issued with an extended table (which will be given hereafter), by the celebrated practical electrical engineer, Latimer Clark. In this report, one of the most striking features in the actual information tabulated, is the immensely superior insulating qualities of Hooper's core, as compared to gutta-percha. The Ceylon cable (already referred to) shows an insulating power twenty times better than the best gutta-percha cable mentioned in the table; and some of Hooper's core, supplied for Indian purposes, stands as high as 22 to 1, in respect to superior insulation, compared with gutta-percha. As regards the inductive capacity (that we have already, in part, treated on when we spoke of the injurious effects of induction in the cable wire, caused in long lines on land or submarine cables) in retarding the current, Hooper's material has 15 per cent. less of that inductive capacity than the lowest of our present gutta-percha cables; or, in other words, a Hooper's insulated cable can convey messages 15 per cent. faster than the best gutta-percha insulated wire.

As we shall presently point out, it is not considered by all as absolutely necessary that the exterior of the gutta-percha coating should be covered with iron or steel wires. The cable hastily laid between Varna and Balaclava, and used during the Russian war of 1854—'56, was simply a single wire coated with gutta-percha, but having *no* external coating of wires twisted around. Allan's system of ocean telegraphy dispenses, in the construction of the cable, with such a coating.

As a universal rule now, however, in laying all submarine cables, such a coating has never been dispensed with; for, of course, the elasticity of both the copper wire and of the gutta-percha surrounding it, is such as would, in many cases, tear the cable asunder. In laying the Atlantic cable of 1866, the strain was often four tons and upwards: and although the cable was protected by external wire, and of the best manufacture, still it was constantly feared that it would part.

Of course, it is a matter of great importance, also, to protect such an external coating from corrosion. Generally, a deep land cable is so protected by the fact that it is excluded from atmospheric action; but in most, galvanisation is had recourse to, as already explained at p. 501, *ante*.

The following is an account of another method, patented by Mr. Latimer Clark, intended to protect cables from corrosion. We are indebted for their description to the proprietors of *Engineering*:—

"The necessity for protecting the outside iron wires of submarine telegraph cables from corrosion is now generally admitted. Galvanising effectually protects them from this action during all the operations of the manufacture, testing, and passage of any cable to its destination, and, where the cable is eventually submerged in certain localities, also for a considerable period after submergence.

"The galvanised iron wires of the Hague cables, laid in 1853, were found, even six and seven years after submergence, for lengths of thirty and forty miles, near the Dutch coast, as perfect as the first day they were manufactured. The wires of the shore ends of the Red Sea cable, which were galvanised, were found quite perfect even up to their junction with the main or 'deep-sea' part, which was found very much corroded even close to this junction.

"Where cables have to be retained for a considerable time after manufacture, whether in water or exposed to rain before final submergence, as in the case of the Atlantic cable of 1857' which was manufactured in 1856, and not finally submerged until 1858; or in the case of cable kept in stock for repairs, galvanising is essential, and answers exceedingly well, keeping the wires of their full strength throughout, besides being clean to handle in splicing, or dealing with in any other way on board ship.

"In many localities, galvanising, though it may add a little to the life of the wires, does not eventually prevent corrosion; and in others, still more deadly to submarine telegraphy, the cables appear to rest on substances which are electro-negative to iron, and which entirely eat through the stoutest iron wires with surprising rapidity for distances varying from six or seven inches to as many feet. Cables were thus weakened in places to such an extent, in some cases, as to leave positively no iron at all for a few inches, whilst leaving the next hundred fathoms on each side quite perfect; and the slightest strain from a ship's anchor, a trawl, the movement of the water, or the weight of the parts on each side of the weak place, would give the *coup de grace* and sever the cable.

"A further protection than galvanising is necessary; and Mr. Latimer Clark patented, some years ago, the plan of protecting the iron by a serving of hemp strands steeped in hot pitch or bitumen. The first cable so covered was the cable from the Isle of Man to St. Bee's Head, laid in October, 1859.

"A cable, sixty-three miles in length, protected by this method, was laid in 1862, between

Pembroke and Wexford; and a portion of the cable laid between Lowestoft and Zand-vort, in the same year, is protected in a similar manner.

"A further improvement was afterwards made by applying the bitumen mixed with silica direct to the iron wires, this being covered with a serving of untarred hemp, through which the warm bitumen forced itself; a second application of the compound being applied and followed by a serving in the reverse direction to the first. The process was afterwards modified by applying the hemp serving first, and then the bitumen, as it was found that the latter did not easily adhere to the cold iron wires; the second serving being in the same way followed by the last application of compound. In either case the whole is smoothed and shaped by hot tongs and rollers: the whole forms a solid cylindrical coating of bitumen, firmly bound together by the hemp strands. The Persian Gulf cable, and several other cables, are thus protected.

"Mr. Clark has made a further improvement in his method. Instead of servings composed of 6, 8, or 12 strands laid on by separate bobbins, two broad strong webbings of hemp are substituted, and wound round the cable in the same manner that telegraph wires are taped for use in underground work. The webbing is sufficiently open in its mesh to allow the bitumen to press up through it, and thus sticking to the next layer, form, as it were, an innumerable number of rivets binding the two layers together.

"The advantages over the former system appear to be considerable. The webbing is much stronger, and would stand more abrasion than the separate hemp strands."

We have now sufficiently considered the chief points involved in the construction of a submarine cable. In respect to the mechanical operations of its manufacture we cannot enter. Generally, little difficulty will be experienced, by any of our readers, in getting an introduction into such works as those of the Gutta-Percha Company, Glasse and Elliot, Henley, Newall, Varley, Siemens, and others. At most of these firms the operation of making cables is largely carried on; whilst, at the factories of others, instruments that will have subsequently to be described, are made. A visit to either will afford an intelligent person much interest; and we can assure him, if intelligent and willing to be instructed, an urbane reception.

As just named, the late Mr. Allan, a celebrated electrician of the Adelphi, London, entirely objected to heavy sea cables, as opposing, by their weight in laying down, the very condition on which their subsequent success depends; that is, freedom from any chance of impaired insulation by stretching the insulating coat, or danger of fracture of the exterior one by the strain that the cable undergoes as it is laid. Although Mr. Allan's system has not been adopted on the large scale, it was proposed to be followed out in making a new Atlantic telegraph between England and America, *viâ* the Azores; hence a brief description of his plan will be desirable. His method of indicating signals, resembles, but is an improvement on, that of Morse; but to describe it here would anticipate another portion of our subject.

Mr. Allan claimed for his principle of deep-sea telegraph cable, that it combines the maximum of conducting power, insulation, strength, flexibility, and durability, with the minimum of weight, bulk, cost, and risk in submergence. He adopted the solid copper wire as giving the greatest amount of conducting power, with the least amount of inductive surface. The strand of copper wire used for ordinary forms of cable, presents considerably more surface than would be obtained with the same amount of conductivity in a solid copper wire; but it is found safer to sacrifice a small amount of speed, owing to the increased surface, than to run the risk of a fracture in the solid copper conductor. Having obtained the best soft solid copper wire, he surrounded it with small steel wires of the best quality, laid on with a slight spiral; and this forms the inextensible core or conductor, and also the strength of the cable. This core, or backbone of the cable, is then insulated with separate layers of gutta-percha, or india-rubber, or any other combination of the two; but it was Mr. Allan's opinion, that none of the failures in deep-sea cables ought to injure the reputation of gutta-percha as an insulator; and his confidence in its suitability for submarine telegraphy remained unshaken, provided it be applied to the conductor with the necessary amount of care, and not submitted to any crushing or stretching process before it reaches its ocean bed. The insulated core is then clothed with a slight covering of hemp, or any other cheap material, saturated with marine paint; and this completes the deep-sea cable.

The true mechanical test of a submarine cable, is to ascertain the number of fathoms of its own length it will sustain in water without elongating to any serious extent. If the conductor, or metallic portion of the cable, be small, then the cable may sustain an enormous length of its own weight in water, and still not be at all suited for a long distance, because of the insufficiency of conducting power. In this respect Mr. Allan's cables were excellent examples, with a much larger conductor than most of the other light cables sent in for testing. Mr. Allan's bore a weight nearly equal to 7,500 fathoms, without elongating 1 per cent.; and this may be taken as the weakest link in the chain, for joins in the steel wire abounded. This cable was also tested round a 12-inch wheel, to see if the core would cut through the gutta-percha; and although this ordeal was at least ten times more severe than it could be subjected to in submergence, not the slightest deviation from the centre could be detected.

The following is the report after the experiments were conducted (*Government Report*, p. 28):—"The results shown in a tubular form for Mr. Allan's cables are remarkable. In these cables the strength is given by steel wires laid spirally round the copper conductor, thus using the strength-giving material to form part of the conductor; the area of the conductor is there-

fore increased ; and there is no danger of the conductor knuckling through the gutta-percha from the resiliency of the latter. This addition to the conducting area increases the induction of the cable in the full ratio of the increased area ; but it only increases the conducting power of the cable in the proportion which the conductivity of steel bears to that of copper, which is about one-seventh. To obtain the same capacity for the transmission of messages in a cable of this kind, as in a cable in which copper forms the sole conductor, the dimensions of the conductor must be increased to give the same ratio of conduction to induction. The insulating material, of course, requires protection in these as in other cables." The latter portion of this report we consider scarcely correct. We have now before us a specimen, in which the compound conductor has no greater surface than the ordinary copper strand of the same conducting power. We intended giving an illustration of this principle of cable ; but it is so few in parts, that we can readily convey it to our readers, by simply saying that it is composed of a No. 8 soft copper wire, surrounded with twenty-five No. 25 best steel wires ; this is insulated with four separate coatings of best gutta-percha, and then finished in a skin of hemp, merely to protect it during submergence : the conducting power of the core is equal to 520 lbs. of copper, and it is insulated with 550 lbs. of gutta-percha per nautical mile ; in diameter it measures five-eighths of an inch ; weight, per naut. in ship, 13 cwt., with a specific gravity of 1·7; and it is calculated to bear 7,500 fathoms of itself in water, without elongating 1 per cent. "Mr. Allan considers this cable suitable for a distance of 2,000 nautical miles, and a depth of 3,000 fathoms; the shore ends, of course, to be heavily protected. A cable of this description has the great advantage of being very simple to manufacture ; in fact, it could be entirely finished by the manufacturer of telegraph cores. There are many instances of the gutta-percha core receiving injury during the process of iron wire covering, which have only been detected after the cable has been submerged."

In paying out a submarine cable from the hold of a ship, it is of the utmost importance that the insulation should be constantly tested ; for if at any moment it be impaired, and the faulty part be allowed to slip overboard, all the labour previously incurred would be lost, and possibly the cable sacrificed. This occurred in the first Atlantic telegraph of 1858, which was altogether a gigantic blunder, in respect to its manufacture and all other circumstances. This is a subject which we shall afterwards deal with.

The method of paying out a cable is extremely simple in principle, but of an arduous character in practice. As it is of a purely mechanical nature, we need not enter into its discussion here. The general plan is, to bring up one end of the cable from the drum, and attach it to the thick shore end, connecting the wires of each cable very accurately ; covering the joint with the insulating substance and the external protecting wires—making, in fact, the two cables, electrically and mechanically, one. The cable, passed from the hold, is passed over drums; and the speed at which it is allowed to pass into the water, is regulated by breaks applied to the drum machinery. Of course, when a great length of cable hangs over the stern of the vessel, from which part it leaves the ship, the strain on the drum is very great; and the amount of this is ascertained by a dynamometer, which indicates the weight hanging, and, consequently, the force of the strain very accurately. On the management of the break will depend the safe laying of the cable; for it is evident, that if the speed of the drums be suddenly stopped or ill regulated, the cable will almost certainly snap. A vivid account of the laying of the Atlantic cable was written by Dr. Russell, to whose work we refer our readers for many interesting particulars.

The regaining of a lost cable is, of course, the reverse of such an operation ; but many mechanical difficulties have to be encountered, which, being of a purely engineering character, need not engage our attention. One of the greatest feats on record of the kind was the recovery of the Atlantic cable lost in 1865. This was fished out of the ocean from a very great depth, attached to a new piece of cable, and continued to Newfoundland, and has since been satisfactorily and profitably worked by the company owning that and the cable laid in 1866.

Having thus noticed the chief points of interest in making land wires, and laying submarine cables, we shall conclude this portion of our subject with some particulars of certain submerged cables, before entering on a description of telegraphic instruments.

A table, which will be given at a future page, will afford the reader some idea of many interesting particulars in reference to such cables. The Persian Gulf cable, for many reasons that need not be for the present particularised, has been frequently taken as a model of submarine cables ; and the following remarks on its qualities will be of value to our practical readers. They are extracted from the *Scientific Review* (January 1st, 1866), from an article by Mr. Fleeming Jenkin, F.R.S., etc.

"This cable, being a good example of a submarine line laid in shallow water, and forming an important link in the telegraphic system connecting Europe with India, deserves a special description, and will afford a fit text for some remarks on the good and bad qualities of shallow-sea cables in general.

"In the Persian Gulf cable, the copper conductor weighs 225 lbs. per knot : it is formed of six segmental wires laid together so as to constitute a cylindrical sheaf, and surrounded by a solid tube of copper. The whole, when complete, bears a strong external resemblance to a simple copper wire of 0·108 inch diameter. The object aimed at in this somewhat complex arrangement is to secure the flexibility and tenacity of a strand, combined with the cylindrical form, solidity, and small bulk of a solid wire. Flexibility is wanted, lest the conductor,

in the many bends to which it is necessarily subjected, should force its way through the gutta-percha; tenacity, lest the conductor should snap asunder. The cylindrical form and small bulk give an electrical advantage by diminishing the statical charge, and so augmenting the number of words per minute which can be transmitted through any long sections of the cable. I have not personally tested the mechanical qualities of this peculiar conductor. I do not doubt, knowing the experience of the engineers—Sir Charles Bright and Mr. Latimer Clark, at whose suggestion the form was adopted—that the advantages aimed at are, to some extent, secured; but, unless I am misinformed as to the extra cost of the conductor prepared in this manner, I should prefer to use the old form of seven-wire strand, laying out the money so saved in the purchase of an extra weight of gutta-percha and copper; by which, I think, an equally efficient cable would be procured at the same or at a less cost. This is, however, a simple matter of pounds, shillings, and pence, and would be settled, possibly against me, by the respective tenders for the two forms. A high conducting power, or small specific resistance, was obtained, in the copper used, by paying a premium for merit above a certain standard. The average resistance of the conductor gives, at 24° Cent., a specific resistance of 0·247 B.A. units: that is to say, a foot of wire, weighing one grain, would at that temperature have a resistance of 0·247 B.A. units. The principle followed was excellent. Here, again, the premium, which it is really worth while to pay, depends on the price of the materials of average quality. On short sections, with a core weighing 225 lbs., no premium whatever would be expedient; but in longer cables, the efficiency of the line might easily be increased 5 or 10 per cent. by attention to the quality of the copper, and a handsome premium on the price would amount to less than the extra cost of a corresponding increase in the weight of the copper and gutta-percha. It may be well to remind readers here, that the efficiency of a long cable, as a speaking instrument, is directly proportional to the weight of the gutta-percha and copper used, provided a constant proportion be maintained between the two materials themselves of constant quality; so that, *cœteris paribus*, a long cable with 400 lbs. of gutta-percha, or 400 lbs. of copper, will allow the transmission of twice as many words per minute as a cable with 200 lbs. of copper or 200 lbs. of gutta-percha.

"In the Persian Gulf cable, the gutta-percha weighs 275 lbs. per knot, and measures 0·38 in. in diameter. The ratio of the diameter of the gutta-percha to the copper is 3·48. The average insulation resistance per knot, at 24° Cent., was 193 millions of B.A. units, and the minimum admitted was 110 millions of B.A. units. The average specific resistance of the gutta-percha (referred to unit of volume) was therefore $5{\cdot}906 \times 10^{12}$ B.A. units: by which is meant that the resistance offered by a foot cube of the material to conduction from one face to the other, is 5·906 million million B.A. units.

"The specific resistance referred to the units of length and breadth—*i.e.*, the resistance of a thread one foot long, and weighing one grain, would be $2{\cdot}6 \times 10^{18}$ B.A. units, or about ten million million million times that of the copper employed. The ratio between the properties of the conducting and insulating material is about equal to that between the distance of the sun from the earth, and half a millionth of an inch.

"These numbers, which are of high interest to a few, must be understood by the general public to mean that the quality of the gutta-percha used was excellent.

"A thoroughly good system of electrical tests was carried out, under the supervision of engineers, from the beginning of the manufacture until the cable was laid. The plan of testing the joints in the gutta-percha was especially noteworthy. The leakage through the tested joint was, as it were, bottled up in an insulated Leyden jar for thirty minutes, and then, in an instant, discharged through a sensitive galvanometer. In this way a loss, which, at any given moment, was so slight as to be wholly incapable of deflecting the most sensitive galvanometer, was rendered capable of exact measurement. The plan was quite analogous to measuring the leakage of water from a pipe by measuring how far it would fill a bucket in a given time.

"The gutta-percha was served or covered with wet tanned hemp. In earlier cables the hemp was tarred, not tanned; but Mr. Willoughby Smith pointed out, that the tar, by filling up slight flaws in the gutta-percha, might temporarily mask serious faults, and the use of wet hemp or jute is decidedly advantageous. Round the hemp lie twelve galvanised iron wires, each 0·18 in. in diameter, and these are again covered with a coating intended to preserve them against rust.

"The diameter of the cable, when complete, is $1\frac{1}{8}$ in., and its weight 3·7 tons per knot, or nautical mile of 6,087 yards. The shore ends weighed 10 tons per knot; and a short length, weighing 16 tons per knot, was also used.

"The cable was laid from sailing ships, towed by steamers, instead of from tanks in the steamers themselves. A great saving of expense was thus effected; and much credit is due to Sir C. Bright and Mr. Clark, the engineers, for their boldness in adopting this plan. Water-tight tanks were used in the transports; and the efficiency of the bituminous outer covering in preventing rust, was shown by the absence of all heating when the water was drawn out of these tanks, as had to be done on several occasions—a process which has been proved to be very dangerous to the common unprotected cables, owing to the heat occasioned by oxidation."

In concluding this general notice of submarine cables, their peculiarities, qualities, etc., we must not omit to give to Faraday the credit of having been amongst the first to investigate the causes of those difficulties that occur in submarine telegraphy, arising from induction in the wire.

A detailed account of Faraday's early experi-

ments on this interesting subject, will be found in the third volume of his *Experimental Researches in Electricity*, being a paper inserted in the *Proceedings of the Royal Institution*, January 20th, 1854. It is entitled, *On Electric Induction: Associated Cases of Current and Static Effects.* It will be unnecessary for us to transfer that account to our pages; for since the date when Faraday's views were first promulgated, infinitely more exact and extensive results have been attained; and, as we have already shown, in the case of the Atlantic cable of 1866, the subject has been studied to exhaustion. The wire experimented on by Faraday consisted of copper accurately coated with gutta-percha, and was in the course of construction at the Gutta-Percha Company's works, near London. The following remarks may, however, be quoted as showing the opinions that Faraday held as to the cause of the phenomena of current and static effects noticed in long submarine cables:—

"In consequence of the perfection of the workmanship a Leyden arrangement is produced upon a large scale; the copper wire becomes charged statically with that electricity which the pole of the battery connected with it can supply; it acts by induction through the gutta-percha (without which induction it would not itself become charged), producing the opposite state on the surface of the water touching the gutta-percha, which forms the outer coating of this curious arrangement. The gutta-percha, across which the induction occurs, is only 0·1 (one-tenth) of an inch thick, and the extent of the coating is enormous. The surface of the copper wire is nearly 8,300 square feet, and the surface of the outer coating of water is four times that amount, or 33,000 square feet.* Hence the striking character of the results. The intensity of the static charge acquired is only equal to the intensity at the pole of the battery whence it is derived; but its quantity is enormous, because of the immense extent of the Leyden arrangement; and hence, when the wire is separated from the battery, and the charge employed, it has all the power of a considerable voltaic current, and gives results which the best ordinary electric machines and Leyden arrangements cannot as yet approach."

The sagacity of Faraday thus supplied a sufficient explanation of this association of static and current effects noticed in submarine cables. He anticipated the full discovery of such effects on the large scale, as resulted in laying the Atlantic cable of 1858: and before that was done, we have heard him express, publicly and privately, the opinion that such induction in submarine cables would much militate against their constant and successful use. But since that period, as already noticed, the difficulty has been overcome; and the Atlantic cables of 1865 and others are worked as readily as any on land, and profitably also, considering that the daily revenue is enormous.

Faraday always maintained the close connection subsisting between insulation and conduction; and, sixteen years previous to 1854, he had taught a doctrine that has been fully developed in the facts and phenomena just explained. The following are his words (1838):—

"All these considerations impress my mind strongly with the conviction that insulation and ordinary conduction cannot be properly separated. When we are examining into their nature—that is, under the general law or laws under which their phenomena are produced—they appear to me to consist in an action of contiguous particles dependent on the forces developed in electrical excitement: these forces bring the particles into a state of tension or polarity, which constitutes both *induction* and *insulation;* and being in this state, the contiguous particles have a power or capability of communicating these forces one to the other, by which they are lowered, and discharge occurs. Every body appears to discharge; but the possession of this capability, in a *greater* or *smaller* degree in different bodies, makes them better or worse conductors, worse or better insulators; and both *induction* and *conduction* appear to be the same in their principle and action, except that, in the latter, an effect common to both is raised to the highest degree; whereas in the former, it occurs, in the best cases, in only an almost insensible quantity." Thus lucidly did Faraday lay out the principles that, a quarter of a century afterwards, were adopted to meet the inductive difficulties of submarine cables, and convert the obstacle into an advantage.

After explaining the principles of lateral induction, he goes on, in the paper of January, 1854, to remark on the velocity of electricity in its passage through a conductor:—

"Admitting that conduction through a wire is preceded by the act of induction, then all the phenomena presented by the submerged or subterranean wires are explained, and, in their explanation, confirm, as I think, the principles given. After Mr. Wheatstone had, in 1834, measured the velocity of a wave of electricity through a copper wire, and given it as 288,000 miles per second, I saw, in 1838, upon the strength of these principles, that the great velocity of discharge through the *same wire* may be greatly varied by attending to the circumstances which cause variations of discharge through spermaceti or sulphur. Thus it must vary with the tension or intensity of the first urging force, which tension is charge or induction. So if the two ends of the wire, in Professor Wheatstone's experiment, were immediately connected with two large insulated metallic surfaces exposed to the air, so that the primary act of induction, after making the contact for discharge, might be in part removed from the internal portion of the wire at the first instant, and disposed for a moment on its surface jointly with the air and surrounding conductors, then I venture to anticipate that the needle-spark would be more retarded than before; and if these two plates were the inner and outer coating of a large jar, or a Leyden battery, then the retardation of that spark

* Of course here Faraday speaks of the cable he employed. The area, &c., of the Atlantic cable has already been mentioned in a previous page.

would be still greater." Now this is precisely the case of the submerged or subterraneous wires, except that, instead of carrying their surfaces towards the inducteous coatings, the latter are brought nearer the former: in both cases the induction consequent upon charge, instead of being excited almost entirely at the moment within the wire, is to a very large extent determined externally; and so the discharge or conduction, being caused by a lower tension, requires a longer time. Hence the reason why, with 1,500 miles of subterraneous wire, the wave was two seconds in passing from end to end; whilst with the same length of air wire the time was almost inappreciable.

"With these lights it is interesting to look at the measured velocities of electricity in wires of metal, as given by different experimenters.

Table of the Velocity of Electricity through Wires, as measured by—

	Miles per Second.
Wheatstone, in 1834, with copper wire	288,000
Walker, in America, with telegraph iron wires	18,780
O'Mitchell do. do. do. . .	28,524
Fizeau and Gonnelle, copper wire . .	112,680
Do. do. iron wire . .	62,600
A. B. G. copper wire on the London and Brussels Telegraph	2,700
A. B. G. copper wire on the London and Edinburgh Telegraph	7,600

"Here the difference in copper is seen, by the first and fifth result, to be a hundredfold. It is further remarked, in Liebig's report of Fizeau and Gonnelle's experiments, that the velocity is not proportional to the conductive capacity, and is independent of the thickness of the wire. All these circumstances and incompatibilities vanish as we recognise and take into consideration the lateral induction of the wire carrying the current. If the velocity of a brief electric discharge is to be ascertained in a given length of wire, the simple circumstances of the latter being twined round a frame, in small space, or spread through the air in a large space, or adhering to walls, or lying on the ground, will make a difference in the results. And in regard to long circuits, such as those described, their conducting power cannot be understood; whilst no reference is made to their lateral static induction, or to the conditions of quantity and intensity which then come into play, especially in the case of short or intermitting currents, for their static and dynamic [conditions] are continually passing into each other."

In 1855, in a paper entitled, *Further Observations on Associated Cases in Electric Induction of Currents and Static Effects,* Faraday entered further into this question, especially in relation to the view of Melloni. But we need not occupy space for detailing his observations; for, as already remarked, Faraday obtained all his results long before the Atlantic cables were laid; and, in 1866-'67, he had entirely lost the power of reasoning on, and still more of studying, the phenomena that had been discovered.

As an appendix to our remarks on land lines suspended on poles, and buried beneath the ground (as described at a previous page, the following remarks on the effects of storms on telegraph wires will be of interest:—

"Early in 1868, the telegraph lines in this kingdom suffered considerably; and in the west of England much inconvenience was felt. The posts along the Lancashire and Yorkshire, and the Manchester, Sheffield, and Lincolnshire Railways, were blown down, putting a stop to all telegraphic communication between Leeds, Wakefield, Manchester, and other large towns. The telegraph service of Europe, too, suffered acutely. About one-third of the French wires and posts, it is said, required repair. In France the length of the telegraph wires is over 100,000 kilometres, at an average of twenty pounds per kilometre. To erect one-third of this length would cost £700,000; and supposing the iron wire of the lines to be uninjured so that it might be used again—an assumption which is questionable—the damage done to the French telegraphs by the storms would necessitate an expenditure of at least some hundreds of thousands of pounds. This damage could not have occurred to buried wires. The remedy, therefore, is obvious.

"Under-ground telegraphs were amongst the earliest introduced into England; but they got into discredit, partly because their form was favourable for induction, and therefore allowed a considerable retardation of signals, and partly because, when laid, they were found after a while to be wanting in insulating capacity. But these difficulties improved manufacture, new systems, and more delicate instruments, have got over. Nor is the point of relative cost one which gives overhead lines the least advantage. In some parts of Europe under-ground wires are ordinarily the cheaper of the two. Instance the French under-ground lines manufactured and laid down for the Administration du Telegraph, by Messrs. Rattier and Co., of Bezons, near Paris.

"Mr. Robert Sabine, whose abilities as a telegraph engineer are well recognised, thus describes these lines in the official report on telegraphy as represented in the Paris Exhibition, made by him to the Committee of Council on Education:—

"'For the lines underneath the streets, iron tubes are employed to protect them against mechanical injury, whilst they also prevent the circulation of air, and retard the deterioration of the gutta-percha by oxidation. The tubes are like those used for gas, of cast-iron, in lengths of 2·3 metres, the diameters being proportioned to the number of wires in them. They are planted in a trench one metre deep. The separate lengths are connected up with lead joints, and at distances of from 50 metres to 150 metres a tube is inserted of larger diameter, which slides over the ends of the two neighbouring tubes, so that by pushing it back the lines can at any time be got at. These places are also used for drawing the cables through. This is done in lengths of 400 metres, the cables being

well covered with powdered talc, to reduce the friction against the sides of the tubes. Five men are employed to plant the lines, and are said to be able to complete a statute mile per day.

"'The average cost to the French government of a line of sixty-three wires, in nine cables of seven wires each, contained in an iron tube 120 mm. diameter, is as follows:—

1. Cast-iron tubes, including trench, laying down, and covering up .	8,000f.
2. Nine cables (of each seven conductors), at 2,900f. per kilometre .	26,000f.
Total	34,000f.

Taking sixty-three wires, therefore, per kilometre of wire, 541f., or less than £35 per statute mile.'

"Overland wires cost nowhere less than this, and we have known it considerably exceeded. In Germany, where underground telegraphs are being widely introduced, cables containing gutta-percha-covered copper wires are used, protected externally with a sheathing of hemp and iron wires. A very common form, manufactured by Messrs. Felten and Guilleaume, of Cologne, for the Prussian telegraph direction, is that containing seven conducting wires, with sixteen iron wires as protection. This cable costs twelve to fifteen silver groschens per foot (German). There are still cheaper things than these."

In 1881 some very interesting facts were published on the effects of the Aurora Borealis on land wires and submarine cables. They appeared in the *Elektrotechnische Zeitschrift.* Professor Foerster, director of the observatory in Berlin, points out the great importance of the careful study of earth currents, first observed at Greenwich, and now being investigated by a committee appointed by the German Government. He further points out, according to Professor Wykander, of Lund, in Sweden, that a close connection exists between earth currents, the protuberances of the sun, and the aurora borealis, and that the nearly regular periodical reappearance of protuberances in intervals of eleven years coincides with similar periods of excessive magnetic earth currents and the appearance of the aurora borealis. The remarkable disturbing influences on telegraph wires and cables of the aurora borealis observed from the 11th to 14th of August, 1880, have been carefully recorded by Herr Geh. Postnath Ludwig in Berlin, and a map of Europe compiled, showing the places affected, with the extent to which telegraph wires and cables were influenced and disturbed. Although the aurora was but faintly visible in England and Germany, and in Russia only as far as 35 deg. north, disturbing influences were reported from all parts of Europe, the Mediterranean, and Africa, and even Japan and the east coast of Asia. As far south as Zanzibar, Mozambique, and Natal disturbances were also noticed. They were in Europe most intense on the morning of August 12th, when they lasted the whole day, and increased again in intensity towards eight o'clock in the evening, while they suddenly ceased everywhere almost simultaneously. Scientific and careful observations were only taken at a few places, but the existence of earth currents in frequently changing direction and varying intensity, was noticed everywhere. Long lines of wires were more affected than short ones, and although some lines—for instance the Berlin-Hamburg in an east-west direction—were not at all influenced, no general law was noticed according to which certain directions were freed from the disturbing influence. While for instance the Red Sea cable was not noticeably affected, the land line to Bombay, forming a continuation of this cable, was materially disturbed. The Marseilles-Algiers cable, so seriously influenced in 1871, showed no signs at all, but as may be expected, the north of Europe suffered more than the south, and in Nystad, Finland, the galvanometer indicated an intensity of current equal to that of 200 Leclanché cells.

Since thunderstorms are generally local, it is only natural that their effect upon telegraph cables should also be confined to one locality. Numerous careful observations, carried out over considerable periods of time, show that the disturbing influences of thunderstorms on telegraph lines are of less duration and more varying in direction and intensity than those of the aurora borealis. Long lines suffer less than short lines; telegraph wires above ground are more easily and more intensely affected than underground cables. It is, however, possible that this is mainly due to the fact that in the districts where strict records were kept, in the German Empire, most of the long lines are underground cables, while most of the short local lines are overground wires. The results of the disturbances varied; in Hughes's apparatus the armatures were thrown off, lines in operation indicated wrong signs, dots became dashes, and the spaces were either multiplied in size or number, according to the direction of the earth currents induced by the thunderstorms. Since these observations extended over nearly 2,000 cases, some conclusions might fairly be drawn from them. For the purpose of a more complete knowledge on this subject, Dr. Wykander recommends a series of regular observations on earth currents to be carried out at different stations, well distributed over the whole surface of the globe, these observations to be made between six and eight A.M., and at the same time in the evening. Special arrangements to be made at various stations to record exceptionally intense disturbances during the phenomena of the aurora borealis, notice to be taken of time, direction, intensity, and all further particulars. Since this question appears to bear a considerable amount of influence on underground cables, it is one that deserves serious attention before earth cables are more generally introduced.

For the two following tables we are indebted to that able electrician and telegraphist, Mr. Clark. They afford information of the greatest value to the practical telegraphist. The last table is also of great interest in connection with our present British Postal-Telegraph system.

Table of Submarine Cables.

DESCRIPTION OF CABLE.	Length Laid.	Diameter.			Weight per Knot.				Resistance of Conductor, at 24° Cent.		Resistance of Dielectric, at 24° Cent.		Electrostatic Capacity.		Approximate Resistance per Knot when laid, irrespective of Temperature and Pressure.		
	Knots.	Copper d Mils.*	Core D Mils.*	Logarithm of $\frac{D}{d}$	Copper lb.	Dielectric. lb.	Iron Wires. Tons.	Completed Cable. Tons.	Resistance per Knot. Ohms.	Specific Conductivity. Pure Copper =100.	Resistance per Knot. * Megohms	Relative Specific Resistances. Persian Gulf = 1.	Electrostatic Capacity per Knot. *Farads.	Relative Specific Inductive *Capacity. Persian Gulf = 1.	Resistance of Dielectric. *Megohms.		Resistance of Conductor. Ohms.
1. Malta and Alexandria Cable. Conductor, a seven-wire strand. Eighteen iron wires, 120 miis diam. (Laid 1861.)	1330	153	463	0·48089	400	400	1·68	2 13	3·49	85·39	115	0·679	—	—	Malta, Tripoli Tripoli, Benghazi Benghazi, Alexandria	242 192 151	3·59 3·56 3·54
2. Persian Gulf Cable. Segmental conductor. Twelve iron wires, 192 mils diam. Exterior covering of asphalt compound. (Laid in 1864.)	1148	110	380	0·53839	225	275	3 06	3·73	6·25	84·79	190	1·000	0·3486	1·000	Fao-Bushire Bushire, Mussendom Mussendom, Gwadur Gwadur, Kurrachee	495 326 342 239	6·46 6·21 6·40 6·30
3. Hooper's Cable for river-crossing in India. Conductor, a seven-wire strand. Twelve iron wires, 200 mils diam. (1865.) . .	146	110	380	0·53839	180	330	3·3	3 8	6·98	94·9	8064	42·420	0 2719	0·812	—		—
4. Atlantic Cable. Conductor, a seven-wire strand. Ten steel wires, 95 mils diam. Each wire covered with tarred Manilla hemp. (Laid 1865.)	1896	147	467	0 50200	300	400	0·632	1·75	4·27	93·08	349	1·968	0·3535	0·995	2945		4 01
5. Persian Gulf Cable. (Additional length.) Solid conductor. Twelve iron wires, similar to No. 2. Exterior covering of asphalt compound. (1866.)	160	110	380	0·53839	225	275	3·06	3·73	6.01	88·17	395	2·079	0·3312	0·950	—		—
6. Ceylon Cable. (Hooper's core.) Conductor, a seven-wire strand. Twelve iron wires, 200 mils diam. Exterior covering of asphalt compound. (Laid 1866.)	35	110	380	0·53839	180	330	3·3	3·3	7·52	88·09	7949	41·840	0·2775	0·829	7000		—

7. **Core for India.** (Hooper's core) similar to No. 6. No iron covering. (1866.) . .	40	110	380	0·53839	130	330	—	—	7·59	87·27	8526	44·870	0·2782	0·831	—	—
8. **Atlantic Cable.** Conductor, a seven-wire strand. Ten steel wires similar to No. 4, each covered with white Manilla hemp. (Laid 1866.)	1852	147	467	0·50200	300	400	0·632	1·50	4·20	94·63	342	1·932	0·3535	0·995	2437	3·89
9. **England and Hanover Cable.** Containing four insulated wires. Conductors, a seven-wire strand. Twelve iron wires, 205 mils diam. Exterior covering of asphalt compound. (Laid 1866.)	224	87	280	0·50764	107	150	8·003	10·94	12·07	92·32	239	1·333	0·3447	0·989	1010	11·71
10. **Placentia Bay and Sydney Cable.** Conductor, a seven-wire strand. Twelve iron wires, 148 mils diam. (1867.)	112·1 188·7	102	348	0·53298	150	230	2·15	2·5	8·958	88·73	455	2·421	0·3566	1·050	Placentia and St. Pierre 4498 St. Pierre and Sydney 4257	8·32 8·34
11. **Cuba & Florida Cables.** Havanah to Key West . Key West to Punta Rassa (Conductor, a 7-wire strand. 12 iron wires, 148 mils diam. (1867)	125·4 119·9	87	290	0·51229	107	166	2·1	2·5	12·38	90 01	464	2·568	0·3507	1·005	1268 175	11·83 12·37
12. **New Zealand Cable**—Lyall Bay to Disaster Point. Containing four insulated wires. Conductors, a seven-wire strand. Ten iron wires, 300 mils diam. Exterior covering of asphalt compound. (Laid 1866.)	42	87	289	0·52138	107	166	7·45	9·1	12·46	89·43	317	1·72	0·3297	0·962	—	—
13. **South Foreland and La Panne Cable.** Containing four insulated wires. Conductors, a seven-wire copper strand. Ten iron wires, 331 mils diam. Exterior covering of asphalt compound. (Laid 1867.)	47	87	256	0·46872	107	120	7·7	9·7	12·48	89·29	217	1·31	0·3700	0·970	1183	13

* Note.—The "Mil" is the $\frac{1}{1000}$th part of an inch. The Megohm = one million ohms. The Farad is the standard unit quantity of electricity as determined by the Committee on Standards of Electrical Resistance, appointed by the British Association; it is that quantity of electricity which, with the unit electro-motive force, passes through a resistance of one Megohm in one second. The unit of electro-motive force does not differ greatly from that of a Daniell's cell. The inductive capacity of a strand is assumed as 5 per cent. less than that of a solid wire of the same diameter, and has been so allowed for in calculating the relative capacities. The following empirical data may be found sometimes useful for calculating the approximate weight of cores: 54 circular mils in sectional area of copper, 69 circ. mils of copper strand, 63 circ. mils of iron, 481 circ. mils of gutta-percha, or 401 circ. mils of Hooper's material, weigh one pound per knot. Hence $\frac{d^2}{54}$ gives the weight per knot of any solid copper conductor, and $\frac{d^2}{69}$ of any copper strand; and similarly $\frac{D^2-d^2}{481}$ gives the weight of gutta-percha in any core. $\frac{d^2\,n}{6789}$ gives the weight of iron in cwts. per knot (including lay) for any cable of n wires.

RAILWAY.	Year ending December 31, 1869.					Year ending December 31, 1879.				
			Number of Instruments.					Number of Instruments.		
	Mileage of Poles.	Mileage of Wire.	Speaking.	Block.	Repeaters and Special Signals.	Mileage of Poles.	Mileage of Wire.	Speaking.	Block.	Repeaters and Special Signals.
	miles.	miles.				miles.	miles.			
Brecon and Merthyr	57	119	49	2	...	61	147	30	43	2
Caledonian	398	1,120	196	...	45	961	3,252	1,020	920	362
Cambrian	85	170	25	4	...	173	426	66	88	2
Carmarthen and Cardigan	17	34	16	...	...	19	38	7	11	...
Cheshire Lines Committee	60	158	23	20	19	105	543	117	330	4
Cornwall (South Devon, Cornwall, West Cornwall, and Cornwall Mineral)	201	531¼	90	169	2	327	759	154	206	117
Festiniog	½	½	...	2	...	13¼	29¼	12	6	2
Furness	93	199	50	22	...	100½	320¾	83	122	12
Glasgow, Barrhead, Kilmarnock Joint	6¾	13½	2	...	...	29	103	30	36	23
Glasgow and Paisley Joint	...	20	2	18	2	1¼	33	21	48	54
Glasgow and South-Western ...	234	345	78	8	2	325	1,062	258	236	54
Glasgow and South-Western, City of Glasgow Union	...	...	...	...	...	6	13	3	23	8
Great Eastern (including Tilbury and Southend)	798¼	2,666½	310	122	70	1,062	3,624½	655	643	432
Colne Valley	19	38	7	...	...	...	38	7	...	...
Great Northern	534½	1,574	165	446	2	720	4,190	1,074	2,548	160
Great North of Scotland	283¼	719½	78	56	5	283¾	700½	119	92	...
Great Western (proper)	346	948	261	503	410	1,549	6,428	1,887	1,807	1,865
Great Western, Bristol and Exeter...	132	476	68	98	15	217	671	144	172	63
Greenock and Wemyss Bay... ...	10	20	3	...	...	10	22	8	12	4
Highland	258½	701	75	43	...	400½	1,236¼	147	69	5
Lancashire and Yorkshire	422	1,063	319	65	122	582	3,031	491	1,091	915
London and North-Western ...	1086¼	3,513	626	511	10	1,840	7,684	1,641	3,015	1,715
London, Brighton, and South Coast	79¼	193½	46	...	1	381½	1,698	609	572	339
London, Chatham, and Dover ...	141	659¼	169	367	...	158	738	222	414	414
London and South-Western... ...	659	2,010	239	251	44	774	3,670	515	727	835
London and South-Western—Somerset and Dorset	65	192½	29	44	...	91½	514	54	72	25
London and South-Western—West London Extension...	4½	24	18	26	6	4½	29	22	26	9
Macclesfield, Bollington, and Marple	...	...	...	...	...	11	44	9	28	...
Maenclochog	...	...	...	...	...	8	24	5	6	...
Manchester, Sheffield, and Lincoln	265	489	103	...	...	296	1,173	367	506	76
Manchester, South Junction and Altrincham...	9	43	10	48	24	19	90	19	78	32
Maryport and Carlisle	28	56	5	...	...	28	58	13	8	2
Metropolitan	10	73½	121	160	91	24	201	214	287	204
Midland	783	3,248	306	294	374	1,244	8,082	1,131	3,530	762
Mid Wales	48	96	13	18	...	48	96	19	24	...
Neath and Brecon	(Line worked by staff & Tickets).					11¼	11¼	5	4	...
North British	655	1,366	200	87	13	765	2,384	409	411	88
North-Eastern	804½	2,193¼	282	6	178	1,548¼	6,614	923	2,892	2,435
North Staffordshire	141½	343½	83	206	...	166	431	98	256	70
Oldham, Ashton-under-Lyne, and Guide Bridge Junction	5½	11	3	...	...	5¾	31	17	44	3
Pembroke and Tenby	27½	43	8	...	...	27½	55	10	12	...
Rhymney	29	107	18	27	7	29	107	18	27	7
Severn and Wye and Severn Bridge...	(Tramway in 1869).					25	53	22	28	29
South-Eastern	335	1,494	277	626	...	340	1,618	360	851	147
South Wales Mineral	12	13½	3	...	3	12	13	4	...	3
South Wales, Governor and Company of Copper Miners	3	3	2	2	...	3	3	2	2	...
Taff Vale	50	115	45	2	...	70	189	82	84	29
Whitland and Taff	(Not open.)					14¼	33	5	4	...
			Total			14,889¾	62,099½	13,128	22,411	11,308

In reproducing the preceding table of statistics, for which we are indebted to *Engineering*, it is but right to observe that the figures there given are not offered as absolutely accurate. In a return of this character, it is clear that there must be considerable latitude in the classification of so many forms or characters of apparatus under so few heads, and thus it is pointed out that it is doubtful if the figures shown have been returned to the compiler in every instance upon the same principle. The figures for 1879 have been summed up, because they are figures obtained from the railway companies, and may therefore be regarded as correct. Those for 1869 are in some instances irrecoverable, and in others imperfect, owing to various causes, and respecting which consequently no total has been drawn.

Rapid as has been the growth of the telegraph system under Government control, equally rapid, and in some instances more so, has been its growth upon railways applicable to railway purposes. This is most clearly exemplified in this table by the extension of the systems on the Midland and London and North-Western. Referring to the figures appended to the former, we find that the mileage of poles has increased from 783 to 1,244, of wire from 3,248 to 8,082, of speaking instruments from 306 to 1,131, and of block instruments from 294 to 3,530. Judged by the statistics furnished by Mr. Graves, no company has so rapidly extended its telegraph, and especially its block system, within the past ten years, as the Midland. The London and North-Western with 1,086 miles of poles in 1869, now possesses 1,840, together with 7,684 miles of wire as against 3,513 in 1869. Its block signalling instruments have increased from 511 to 3,015, and its speaking instruments from 626 to 1,641. The North-Eastern also shows a markedly large extension of block—greater in this respect than any other company. The Great Northern, Caledonian, Cheshire Lines, Great Eastern, Great Western, and Lancashire and Yorkshire are also noticeable for the large additions made to those systems. On the whole it would appear that in the course of ten years the railways in England, Scotland, and Wales have increased their mileage of wire from some 27,000 miles to 62,000, and their block instruments from about 4,400 to 22,411.

At a future page statistics of the present telegraph system of the United Kingdom will be given. It may be interesting to notice that at the end of 1880 the total paid-up capital of British railways amounted to £728,000,000, an amount about equal to the National Debt.

TELEGRAPHIC INSTRUMENTS USED FOR INDICATING, Etc.

It would be impossible, in our limited space, to describe and illustrate all the apparatus that has been invented to indicate the results of electro-telegraphy. Some have been, and still are, great successes; whilst in many, if we do not say in most cases, failure has been an inevitable result. The early demands on the electric telegraph were trifling to those that now rule its action; and, consequently, its arrival to perfection (if we may so call its present condition) was slow, or, at all events, gradual.

The early use of the electric telegraph, as we have already seen, was almost entirely confined to the satisfaction of railway requirements. As the railway system advanced in development, the agency of the electric telegraph became a matter of necessity. At first most railways were constructed with double lines—that is, a pair for up and down traffic—because, in the absence of an instantaneous mode of communication between each station, it would have been impossible to work the up and down traffic on one pair of rails.

But the electric telegraph renders a single line of rails not only possible, but safe in working; and, as already stated, both on a single and double line, the "block" system has become a rule of working.

One of the earliest forms of telegraph that came into operation was that of the needle telegraph, already referred to at p. 490, *ante*, as having been first patented by Cooke and Wheatstone. Until a comparatively recent date, this system of telegraphy was universal in the British islands; but, like many other inventions, it has had to make way for improvements.

The needle telegraph essentially depends on the fact, that an electrified wire deflects a magnetised steel needle from its ordinary position. Thus, under common circumstances, a magnetic needle points nearly north and south; but so soon as a current of electricity is passed over it, its polar tendencies are suspended, and it is deflected to the right or left hand, according to the direction of the current.

The following cut exhibits a very simple

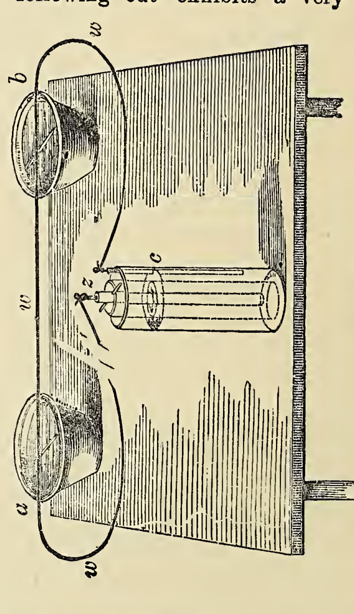


Fig. 269.

means of making what we may call an elementary electric telegraph. *a* and *b* are two basins, partly filled with water, on which floats a needle, magnetised in the usual way. Of course, so long as

the magnetised needles are uninfluenced, they will naturally point to the magnetic north and to the south. But if the current from a voltaic battery be sent over the needles by the wire, *w*, from a cell whose zinc element is represented by *z*, and its copper by *c* in the cut, then the needles will cease to point north and south; they will be diverted right or left of those points, according to the direction of the current.

Consequently, the construction of the needle telegraph is an expansion and adaptation to practical purposes of Œrsted's discovery, made by him in 1819, to the effect, that an electrified wire—that is, conveying a voltaic current near a magnetised needle—deflects the latter from its polar position so long as the current passes.

As already shown in the historical account given of electro-telegraphic progress, the needle telegraph was not the first invented; but it deserves first notice, as being that most greatly used at one time for telegraphic communication.

The earliest form was that of the single-needle instrument. This essentially consisted of three separate parts—namely, the magnetised needle, and its index; the coil that passed over and under the needle, and conveying a voltaic current; and, lastly, a commutator, by means of which the current could be caused to proceed in two different directions, and thus deflect the needle right or left, as might be, and constantly was, required in working the instrument.

First, as regards the needle. It was suspended vertically, and in such a manner, that, when unacted on by the voltaic current, it kept

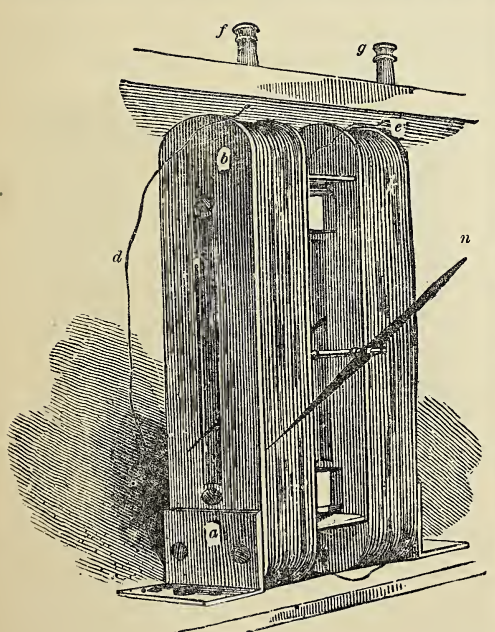


Fig. 270.

a perpendicular position. The coil consisted of numerous convolutions of fine covered copper wire, wound on a frame in such a manner that the needle could oscillate right and left, moving, at the same time, an index, that worked simultaneously with the needle, but external to the coil, and on the face of a disc on which was printed the code of signals.

In the preceding cut the arrangements of the coil, wire, &c., are illustrated. *n* represents the north pole of the needle, diverged to the right-hand side, under the supposition that a current is passing from the top to the bottom of the coil, *b a*. Two wires, *d e*, attached to two binding-screws, *f g*, shown at the top of the cut, are the two means of connecting the coil with the cell or battery producing the current.

In the following cut, an illustration is given of the method of mounting such a coil, certainly in

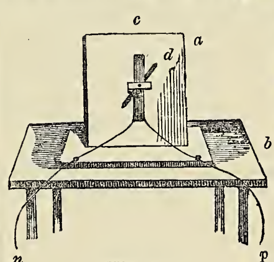


Fig. 271.

a rough way; but by constructing such an instrument, or rather a pair of them, the action of the needle telegraph will be readily understood. *a* is an upright board, a foot square, mounted vertically on a base, *b*; a coil, *c*, is formed by winding fifty feet of fine copper wire, covered with cotton or silk, on a frame somewhat similar to that which is used by anglers to hold the line; but the particular form of which has been already illustrated in Fig. 270, *ante*, representing the coil and needle. *d* is a magnetised piece of steel (as, for example, the ordinary needle of a mariner's compass), so arranged that it shall turn readily inside the coil, *c*, right or left, when a current is passing through *c*, but keep a perpendicular position when no current is passing: *n p* are two wires terminating the coil, and intended to convey the battery current to *c*.

Now, if two such instruments be constructed, and placed at opposite ends of a room, connected with a wire extending from one coil to the other, whilst two other wires are brought, one from each of the two extremities of the coil, and connected with a single cell of a voltaic battery, the moment a current passes, the needle of each of the instruments is instantly deflected in the same direction—viz., to the right, if the current pass over the needle from the top to the bottom of the coil; and to the left if in an opposite direction. The moment the current is cut off by removing one or both of the wires from connection with the battery, at the same instant the needles, being no longer influenced by a voltaic current, return to their previous vertical position. We may here add, that many of the London and provincial instrument-makers sell, at a cheap rate, such an apparatus as we have suggested.

But all that has been hitherto stated or illustrated by us, simply shows that two signals are thus readily passed by the needle apparatus—that is, by a deflection—one to the right, and the other to the left. Such a limited number would

be of little use in practice. It might answer very well for communicating a positive and negative signal; as, for example, a deflection to the right might be understood as "yes," and to the left as "no." Or supposing, as was the case with the London termini of some of the early railways, at one of which was fixed a steam-engine, to draw up a train by means of a rope (say as used to be done on the Blackwall Railway), then a deflection to the right might communicate a signal instantly to "go on;" and when the wire had been nearly all unwound at one terminus, and the train had reached the most distant one, a deflection of the needle to the left being transmitted, might signify "stop."

A code of signals, however, soon became adopted that extended this mode of telegraphing for every possible purpose, rendering it a fact of universal operation; for it is evident that if the needle or needles could be rapidly deflected either way, by a combination of such deflections signals corresponding to letters, or even words, might be readily transmitted for any required length of message.

For example, suppose two deflections to the left were determined to represent A; three to the left, B; four to the left, C; and, on the other hand, one to the right represented M; two to the right, N; three to the right, O; four to the right, P; and *one* to the left, a universal signal, say marked thus +; it is evident that eight different signals could thus be communicated, representing seven letters of the alphabet.

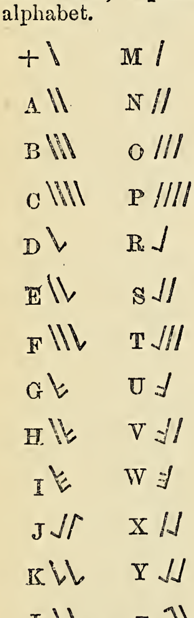


Fig. 272.

But in the latter there are twenty-six; hence additional forms of combined signals are necessary.

This difficulty, however, was readily got over by uniting deflections in pairs, threes, and fours. Thus, one to the right and one to the left, forming a pair of combinations, might represent the letter D; one to the right, and two to the left, E; and so on. Thus this combination could be so adapted as to represent every letter in the alphabet; and, consequently, to give a mode of signalling that should answer every imaginable purpose.

A code so produced is represented in the annexed cut. The first signal, +, which has a variety of applications, is produced by deflecting the needle once to the left; A is represented by two deflections to the left; and so on: C is shown by four deflections to the left. Opposite to these, in the code, we notice, M, N, O, P, represented by one, two, three, and four deflections respectively to the right. At D commences the combined signals, for the little line indicates one deflection to the right, whilst the long one shows one to the left. A simple inspection of the code, as thus given, will be sufficient to make the reader understand all the signals without our giving a description for each further separate signal.

The next question to settle is, how these rapid changes in deflection can be accomplished? This is done by a commutator, by means of which the direction of the current can be rapidly changed. Numerous forms have been devised for such instruments; but as we are here only describing the general principles of telegraphic instruments, we will not, for the present, go into minute details. The arrangement is such, that by the motion of a handle right and left, the opposite extremities of the coil, and of the poles of the actuating battery, can be reversed in the order of contact, inducing, consequently, a reversal in the direction of the current, which may, therefore, as rapidly as possible, be made to produce the right and left deflection of the needle of the needle telegraphic instrument, at a speed that will allow of the communication of messages of several words per minute.

But soon the single-needle telegraph was not sufficient in its action for the wants of the public and the railway companies. It was followed by the introduction of the double-needle instrument, that, as already remarked, was for a long time the chiefly used instrument of the telegraph companies. In principle and construction it was all but identical with the single-needle instrument, except that, of course, it was furnished with a double set of needles and coils that could be worked simultaneously, halving at least the time required to forward a message. The following engraving will give an idea of the external appearance of the instrument; the two

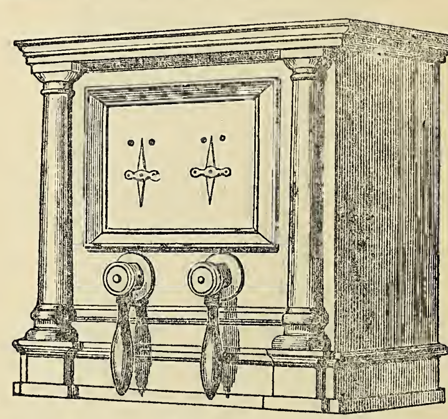


Fig. 273.

needles being shown on the face or disc, on which, in the instrument, the code of signals is printed. At the lower part are the two handles, by which the direction of the current over the needles, through the coils, and, consequently, the indication of the message at the distant station, are effected. The small black dots on either side of the needle are pegs, intended to limit the amount of the vibration of the needle

right and left, and, consequently, at the same time to lessen the period during which they would come to rest.

Simple as would seem the arrangements that have been described, a stranger would find much difficulty in attempting to decipher the messages sent by such instruments. All he would notice would be the rapid deflection, right and left, of the needles, that to him, for want of practice, would be absolutely unintelligible. But a little practice soon enables even the tyro in telegraphy to overcome this first difficulty. Precisely the same occurs to the beginner in music-playing from notes. The eye, fixed on the printed sheet, has at first the greatest difficulty to convey to the mind information as to which key (as in a pianoforte) should be struck by the finger. But gradually, through constant practice, a facility of execution is acquired; and thus we often may see the skilful performer rattling over the keys with a speed as marvellous as it is pleasing and effective.

It is precisely the same in respect to the needle telegraph. The operator gradually acquires such dexterity, that he will read the signals as rapidly as he can the letters and words of a book. On this subject Dr. Lardner remarks—

"Different telegraphists have very different powers as to their celerity. These powers depend on practice, as well as upon natural ability and aptitude, and on manual dexterity. Not only is it necessary to transmit the signals in quick succession, but to do so with such distinctness that they shall be readily interpreted, and such correctness as to render repetitions unnecessary. In this respect, telegraphists, having equal practice, differ one from another as much as do clerks—some writing rapidly and legibly; some rapidly, but not legibly; some legibly, but not rapidly; and some neither rapidly nor legibly. The relative ability of telegraphists in this respect is partly mental and partly mechanical, depending as much upon quickness of intelligence, attention, and observation, as upon manual dexterity and address.

"The great liability of delay, arising from failure of the transmitter to render himself understood by the receiver, is rendered manifest by the fact, that in all telegraphs conventional signs are established for the words 'wait,' 'repeat,' 'not understood,' 'understood,' 'proceed,' and the like. When the transmitter is going on faster than the receiver can take down the words or understand them, then the latter remits the sign to 'wait;' and if this sign be several times repeated, the necessity of proceeding slower is apparent. If the receiver mistakes a sentence, word, or letter, he remits the sign to 'repeat.' At the end of each sentence he remits the sign 'understood,' and so on. Now it will be easily conceived that this necessity for frequent interchange of signs between the receiver and the transmitter, must affect, in an important degree, the celerity of transmission; and that its frequency must depend, not only on the abilities of the telegraphic agents, but also on the character of the signs transmitted by the instruments, according as they are more or less obvious and unequivocal.

"It is a remarkable and very curious circumstance, that, independently of the mere celerity, clearness, and correctness of transmission with certain telegraphic instruments, each telegraphist has a manner and character which is so peculiar to himself, that persons receiving his despatch at a distant station, recognise his personality with as much certainty and facility as they would recognise the hand-writing of a correspondent, or the voice and utterance of a friend or acquaintance whom they might hear speak in an adjacent room. The agents habitually engaged at each of the telegraph stations, in this way soon become acquainted with those of all the other stations of the line; so that, at the commencement of a despatch, they immediately know who is transmitting it.

"While the aptitude of the transmitter is partly manual or mechanical, that of the receiver of a despatch is not at all so. In some telegraphic instruments, as will be seen, the presence of a receiving agent is unnecessary, the despatch being written or printed by the apparatus itself. In all instruments, however, which merely exhibit arbitrary signals, expressing letters, numbers, or words, the celerity must depend on the skill, aptitude, and quickness of eyes of the receiver, to catch, and commit to paper, the succession of words or letters as fast as the signals expressing them are produced before him.

"In general, it is much easier to transmit rapidly than to receive rapidly. The transmitter knows beforehand what signs he is about to produce, while each of them comes upon the receiver unawares; and if, in the celerity of their succession, one or more of them escape his eye, he is obliged to guess at either the missed letter or letters, which he can sometimes do with all the requisite clearness and certainty, or he must arrest the transmitter, which he does by giving the sign 'repeat,' and so delay arises."

The following remarks, that continue Dr. Lardner's statements, require certain modifications, in respect to accuracy, at the present day; but such portions as deal with the single and double-needle telegraphs, are equally true now as when they were penned, which was about twenty or twenty-five years ago.

"In telegraphs which work by a series of visible signs, whether they be the deflections of the needle, as in the English instruments [such as we have described in detail, as to their principles of construction and use, in our preceding pages], attitudes of the arms, as in the French State instruments, or pointers directed to the letters or figures on a dial, as in the railway instruments, the celerity of the transmission must be determined by the power of the less able of the two agents, the transmitter and receiver. If the transmitter be able to send the letters more rapidly than the receiver can read and take them down, he must moderate his pace to the limit determined by the power of his correspondent. If the receiver be capable

of reading and taking down faster than the transmitter is able to send the letters, his superior force is useless. He can only write the despatch as fast as he receives it. To send despatches with the greatest advantage of celerity, the agents yoked to corresponding instruments ought to be selected of as nearly equal ability as possible, since the slower of a pair necessarily neutralises the superior skill of his fellow, and the despatch would proceed with equal celerity if he were yoked with a less able correspondent. [Since Dr. Lardner penned the preceding and following remarks, the employment of females has, to a great extent, obviated some of the difficulties to which he alludes.]

"As quickness of hand is essential to the transmitter, quickness of eye is necessary to the receiver.

"In all forms of telegraph which express the letters by signals, such as the needle telegraph, and the French State telegraph, a certain pause is necessary between letter and letter, to prevent the signals being confounded one with another. In the single-needle instrument, the letters being expressed by from one to four deflections of the needle, and in the double needle, from one to two, the mean time of each letter is that of $2\frac{1}{2}$ deflections in the one, and $1\frac{1}{2}$ in the other, the intervals between letter and letter being the same in both. Owing to the slowness of transmission of the single-needle instrument, it is only used between secondary stations, where there is but little business. It must, however, be remembered, in comparing the relative celerity of different instruments, that the double-needle instrument, as well as the French State telegraph, is, in fact, two independent telegraphs, having not only separate and independent transmitting and indicating apparatus, with their respective accessories, batteries, &c., but separate and independent conducting wires. It is, in effect, as if two equally powerful and independent steam-engines were united in the same work, in order to obtain double power.

"In 1850, Mr. Walker made some calculations, with the view to determine the average celerity of transmission, at that time, with the double-needle instrument in the hands of competent operators, and published the results in his work on electric telegraph manipulation. Eleven messages were timed, all of more than the usual length, the shortest consisting of 73, and the longest of 364 words. The total number of words was 2,638, and, consequently, their average length was 240 words. The total time of transmission was 162 minutes, and, consequently, the average number of words transmitted per minute was $16\frac{1}{4}$. The greatest speed of transmission was $20\frac{1}{2}$, and the least $8\frac{1}{2}$ words per minute.

"As it might be considered probable that four or five years' general experience and practice might have improved the ability of the operators, I applied to the secretary of the Electric Telegraph Company, requesting him to cause a sufficient number of messages, transmitted, in the ordinary course of business, with the double-needle instrument, to be timed; which he was so obliging as to do, in June, 1854, and the following were the results:—

Eleven Messages.—Number of words in the addresses	84
Ditto ditto in the messages . . .	160
Total number of words transmitted .	244
Total time of transmission, in seconds	689
Average number of words transmitted per minute	214

"It appears, therefore, that the average celerity of transmission with this instrument had increased in the ratio of about 16 to 21.

"The greatest celerity of transmission in this case was $24\frac{1}{2}$, and the least $16\frac{3}{4}$ per minute."

The Magnetic Electric Telegraph Company commenced by employing the current induced by magnetism, in the form of the magneto-electric machine, which was, however, subsequently substituted by the voltaic battery. On the celerity obtained with the instruments they employed, Dr. Lardner had the opinion that a special action existed in its favour. Our friend, Mr. Gibson, who had the management of the company's branch at Dumfries, N.B., and who had long practised with these instruments, did not, however, countenance such results. He expresses his views to us on the subject, in 1858 and 1866, to the same effect. But on the principles of *audi alteram partem*, we quote Dr. Lardner on the subject.

"The manner in which the magneto-electric current affects the needle in the arrangement adopted by the Magnetic Telegraph Company, being somewhat different from that produced in the common needle instruments, worked by the Electric Telegraph Company, although the systems of telegraphic signals are not essentially different, it appeared to me to be not impossible that the difference between the instruments might more or less affect the celerity of transmission. I therefore requested Mr. Bright, the secretary of the Magnetic Company, to time a series of despatches transmitted in the ordinary course of business. This was accordingly done on the 28th of June, 1854, and the following were the results:—

74 Messages.—Total number of words .	2722
Time of transmission .	$102^{m}\ 8^{s}$
Average number of words per minute .	$27\frac{1}{3}$

"The greatest celerity of transmission attained in this series of messages was $37\frac{1}{6}$ words per minute.

"The entire series consisted of messages transmitted from London to Liverpool, on a pair of double-needle instruments, at different times of the day, and were carefully tabulated. In the series, several messages were included, the transmission of which was exceptionally slow, owing either to the difficult nature of the communications, consisting of long words in private cipher, or of the names of foreign towns, or, in fine, from the inaccuracy or slowness of the transmitting clerk in London. It would seem,

therefore, that this series of messages includes fair conditions for an average result.

"It would, therefore, appear that the needle instruments worked by the magneto-electric current, used by this company, are, *cæteris paribus*, susceptible of greater celerity of transmission than the instruments in which the needles are affected by the common voltaic current, in the ratio of about 27 to 21, or 9 to 7.

"One of the causes which has been assigned to this increased efficiency, is the fact that the needles of the magnetic instruments have a *dead beat*; whilst those of the voltaic instruments, in striking the tops, have a recoil, and vibrate two or three times before they come to rest. Whether this be the real cause of the difference, further experience must prove; but it is difficult to imagine that it can be due to any cause independent of the instruments, seeing the large number of messages from which the average has been computed."

Having thus first disposed of the needle telegraphs, we next turn to those of the Morse kind, which, in America, has long sustained a similar position to that of the needle instrument in the British islands.

At p. 489, *ante*, we have already noticed, in our general history of electric telegraphy, that Mr. Morse, so early as 1832, studied electro-telegraphy, although he had not arrived at any definite results for some years later. What Cooke and Wheatstone have been with us, Morse has been to America; for as the instruments of the former were in all but universal use in Great Britain, in the form of the needle telegraph, so was, and is, the Morse system similarly employed in the United States.

But between the two systems great diversity of character subsists. The needle telegraphic instrument merely *indicates*, by signals, the message that is sent by it; but Morse's, and a great many other modern systems, *register* the message, which thus, consequently, cannot either be tampered with, nor, by the most ordinary care, be misunderstood or misrepresented.

The general principle on which Morse's original system was founded, is that of making a series of lines on paper, or other receiving material, of varying lengths. This is effected by the action of electro-magnets, which supply the mechanical power, and that are kept under control for that purpose, according to the will of the operator. In part, Morse's original system partakes of that of the dot signal; but as a dot is, after all, only a short line, such a definition is inapplicable to any system presumed to differ in respect to the adoption of the dot and line plan respectively. This will be more fully evident when, at a future page, we describe the system that Mr. Allan, Wheatstone, and others have patented in respect to perforated ribbons for the transmission of messages by variously-contrived apparatus.

Morse's early instrument was essentially a combination of clock-work and electro-magnets, the generative power being an electro-magnet, worked preferably by intense cells, such as those of the nitric acid batteries, Bunsen's carbon, or Grove's platina arrangement.

The lengths of the marks, of course, become the indicators of the code of signals; and the following illustration shows those which were early used by Morse.

Code of Signals adopted by Morse.

A -—	U --—
B —---	V ---—
C -- -	W -——
D —--	X -—--
E -	Y --—--
F -—-	Z --- -
G ——-	& - ---
H ----	
I --	Numerals.
J —-—-	
K —-—	1 -——-
L ——	2 --—--
M -——	3 ---—-
N —-	4 ----—
O - -	5 ———
P -----	6 ------
Q --—-	7 ——--
R - --	8 —----
S ---	9 —--—
T —	0 ———

The clock-work arrangement is such as to move a lever, at the end of which is a pencil. A sheet of paper is wound on a cylinder, and on this paper marks are made by the pencil, varying in length, so as to make the code already illustrated in the preceding figure. The internal mechanism of the arrangement is somewhat complicated, but is simply of a mechanical character, identical with that of ordinary clock-work; and, despite many illustrations that we have seen, is not to be understood except by actual inspection of the instrument itself. The improved forms of the instrument will be hereafter noticed.

It is somewhat remarkable, that whilst communication has been so long and quickly established between the New and Old Worlds, two entirely different systems, such as those of Morse in America, and Cooke and Wheatstone's in England, should have simultaneously had so long a patronage by the respective telegraphic companies. But it is evident, that when once a system is adopted by a company, it is a matter of economy to maintain it as long as no positive loss is sustained by its use. Thus, the Electric Telegraph Company, of London, adopted with us, at first, the needle telegraph of Wheatstone; and, gradually, as their business extended, of course that form of telegraph was extended throughout all the branches. The clerks and others became expert in the use of such instruments; the makers of them supplied all their wants; and as more instruments were constructed, economy resulted in their construction, or rather the cost of a greater number of instruments became decreased in a certain ratio. It is, therefore, no matter of surprise, that when a system was once adopted it should have been adhered to for a lengthened period. Hence the reason of the popularity of the Wheatstone

system in our country, and of the Morse, *per se*, in the United States, and, in a modified form, in continental Europe. We shall have more to say on this subject when we deal with the present British Postal Telegraph system.

It is almost impossible, in the multifarious forms of electro-telegraphic instruments, to point out where an invention really began, and where its improvements have ceased. The printing-telegraphs were foreshadowed, or rather originated, by Bain, *cir.* 1850; the electro-chemical at a much earlier date; the perforating by an expansion of the Morse system; and, in fact, to attempt to disentangle such a web of invention, would be to undertake the task of a Penelope.

Allan's Mode of Telegraphy.—At p. 507, *ante*, we have described certain improvements that Mr. Allan suggested in reference to the construction of submarine cables, pointing out that he preferred to give strength to the cable interior, rather than exterior to it. For the object of submarine telegraphy he also proposed a different system of signalling. His suggested method has not been tried on the large scale; and, from difficulties in respect to induction (already so fully dealt with at p. 510, *et seq.*), there can be scarcely a doubt that it would fail if attempted to be employed in long submarine cables, such as Mr. Allan proposed to submerge between Portugal, the Azores, and America, in 1867. Still, out of great respect for the talents of that gentleman, and as a matter of impartiality on our part, we must necessarily give an account of the method proposed by him, and that which was illustrated at the Exhibition of 1862.

At p. 521, *ante*, we described the Morse system in respect to a signal code, as first adopted. In that, dashes of unequal or varying length were employed. Mr. Allan prefers a dot instead of a dash symbol for signalling and receiving. At the signalling extremity, a ribbon of paper has the dots separately punched by a machine; and in this prepared message, when passed into the apparatus for transmission, and the automatic action once commenced, each single punch-hole, as it passes over the tooth of a small rotating spur-wheel, permits of electrical contact being made with the sending machine, and of thereby inducing a perfectly synchronous movement at the receiving extremity of the line wire, and of causing a puncture in the ribbon passing through the automatic apparatus there; so that, at the same instant of time, what is a hole at one extremity, is puncture or emboss at the other.

We next turn to the code of signals, and to the method by which the message is punched or marked on the ribbon.

The following cut illustrates Mr. Allan's method of recording messages, for use either on land or submarine telegraphs. As previously mentioned, the dot system, which he prefers, saves considerable time in transmitting the message.

In the cut, Morse's system is compared with that of Mr. Allan's; and it will be seen that the latter has the advantage in respect to space occupied on the receiving-tape, and that the code of signals is entirely different. The length of the dash is done away with, and the space between them economised. In Allan's arrange-

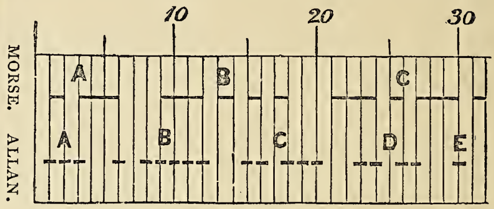


Fig. 274.

ment, 126 currents produce the alphabet; against 164 required in the instrument employed in the system of Morse. The proportion of time is as 196 to 290 for the whole alphabet; and as 33 to 49 for a word; or, generally, about 50 per cent. is saved.

The apparatus employed is called a composing machine. It consists of an oblong mahogany case, eleven inches by eight, and seven inches deep, wherein are mounted a set of keys, thirty in number, resembling those of a piano, or other keyed instrument. The letters of the Roman alphabet are printed on the touch-part of twenty-six of these, leaving four for purposes incidental to the working of the machine—as to convey the fact that the message is understood, &c., &c.

Within the box, and movable by the key levers, are eight punches. A ribbon of paper is made to pass through the composing machine. Now, any person who can read a message has simply to spell out its words upon the keys by depressing each letter-key of the word, and its symbol in the code is punched out at a single stroke. The operation, which is perfectly simple, resembles the act of playing on the piano. The message, on being punched, is passed into the telegraphic instrument, which, from its automatic character, continues to work on till the whole passes through; and the corresponding automatism of the receiving apparatus is brought into play at the same instant.

Further, any one may have his own composing or punching machine, and adopt his own code of signals, by the very simple device of transposing the Roman characters on the touch part of the keys. Secrecy is secured by these means; and the message, on being punched—it may be a government or business establishment—if despatched to the telegraph office, can be at once sent through to the confidential receiver of the same, who is in possession of the cipher to read the message, whilst the telegraph-office clerks know nothing of its import.

Further, this composing machine, taken with the system of telegraphy, of which it forms a part, possesses considerable interest to the newspaper press, as a probable means of cheapening what is a heavy cost in their annual expenses—namely, the telegraphic despatches. A single punched ribbon may be carried simultaneously over any number of sending machines, and the same political news, or parliamentary speeches,

may be sent to half a dozen places from the same centre—say from London—at the same time; and all this may be done by so many boys as there are receiving places.

Again, to receive messages depending upon either visual or audible signals, the clerk must always be in attendance; and when the distance is great, over land or water, so as to embrace many degrees of longitude, that attendance must be unremitting night and day. The clerk, in such a case, is a part of the instrument, and the complement of it: he can no more withdraw himself an instant than he can safely remove from its connections the telegraphic portion of the message system. By the automatic scheme the attendant need not be always present. He may even go to bed; and when he awakes he may find the communications sent in the meantime in the message basket. Further, one attendant at each end of the line wire is all that is now needed; and the sender need be no other than a person of average intelligence, of little experience, and who can, as has been already said, read well. A boy or girl of twelve or fourteen years may do the sending work; and a moderate education and experience are all that is needed to receive, interpret, extend in writing, and distribute correspondence. A uniform charge for messages within a wide circuit belongs to the economy of this system, upon the basis of the plan adopted for our post-office. The Telegraph Company, according to Mr. Allan's scheme, should issue blank and file-books; and any person possessing one such book, has only to write his message on a blank leaf, tear it out, envelop, and drop it into the office-box, when it has instant attention given to it. All this appears quite plain and possible; but the distinguishing features of the mechanism, conjointly with the electrical influence by which it is produced, is not so obvious. According to Allan's plan of signalling, the punctures or "embossings," on the paper at the receiving points, are made by the method of reverse currents, or the positive and negative electric currents are both made effective for marking; and the receiving instrument itself, without any expense of power, makes the distinguishing spaces between the letters; whereas, in other instruments of this kind, small spiral springs are introduced, for the quick and certain recovery of the deflected needle to the neutral position, in order to make spaces. This latter plan is also followed by Digney, a French maker of good repute; but it is objectionable for various reasons; and one of these is the superfluous demand that is made on the electric force to overcome a mechanical resistance, and the possible fluctuations and depressions of battery force, which, from the resistance of the spring, might destroy the signalling power. In the instances of the telegraphic instruments of other makers, reverse currents are employed instead of springs; but, with them, one of the currents is devoted to making the spaces, whereas Allan utilises both, as has been already stated, for marking. By this means he diminishes the number of currents sent through the line wire by upwards of 30 per cent.; and, on the other hand, the gain in point of time, by adopting altogether the "dot" system of marking, is about 50 per cent. This particular will be at once appreciated by the intelligent telegraphist at its proper importance; because, by the arrangement in question, greater signalling power is attained with relatively less expense of electrical force; and besides this, and with especial reference to the application of this plan to long-range submarine telegraphy, greater speed of transmission is also attained. But further, the effective workings of such instruments depend, amongst other things, upon the nice adjustment and suitable condition of the metallic surfaces, which are required to act by making and breaking electrical contact with each other. First, the sending or reversing break is here made to preserve clean contact by a rubbing action, which effectually wipes off any abraded matter which the spark carries over from one terminal point, and deposits upon the other and opposite point. In Allan's "relays," or pole changers, as these instruments may be called, this contingency is very ingeniously provided against. The relays are "sparkless;" and the small disruptive discharge of electricity which takes place on breaking contact is not produced in the relay at all, but in the recording instrument, where the mutual attrition of the metallic surfaces constantly preserves the parts clean. The importance that attaches to this particular will be apparent, when it is remembered that foul contact-points in the relay would soon reduce the action of the battery, which should work it, to inefficiency. By Allan's plan the power of the battery is preserved, and the machinery of the whole line kept open for the transmission of correspondence. Moreover, the absence of the spark in the relay admits of a great increase in the power of the local battery, and therefore of more efficient action in working; whereas the sparkling relay of other makers compels them to use only a very moderate power, so as to injure the operations of the instrument as little and as slowly as possible. This inconvenience, therefore, carries with it a limit upon the energy with which a telegraph line can be worked, without the risk of delaying its action for cleaning the relay at very short intervals of time.

Now, despite the ingenuity that is displayed in the precedingly-described invention, it will be evident to the telegraphist that many practical difficulties will arise in its application even on land lines. In respect to extended submarine cables, it will be sufficient to state that Mr. Allan's arrangements were described as above in 1862-'63, five years after the first Atlantic cable was lost (1858), and before the practical difficulties that arise from induction in a cable were either fully understood or appreciated. From the phenomena and facts since discovered, there is every reason to believe, that whatever merits Mr. Allan's cable system (as described at p. 507, *ante*) may have, the telegraphic system he thus proposes would be valueless in connection with such cables as the Atlantic, or any of great submerged length.

We must, however, do Mr. Allan the justice to state, that so early as 1853, he fully foresaw, as far as then knowledge could permit, the difficulties that might arise from induced currents. Remarking in a pamphlet on *Inland and Submarine Telegraphy*, which we have now before us, and in reference to his cable (already described at p. 507), as destitute of a metallic outer coating, he says—

"In addition to these advantages [stated at the page just referred to], the fact of *no metal being used outside*, renders the conductor [that is, the internal coil of copper wire] in a great degree independent of absolutely perfect insulation, as there is *neither that tendency to charge the wire—which disturbs* the working of the instruments—nor to making the short circuit, in the event of the insulation becoming imperfect, which in submarine conductors, on the present plan, is a defect that is always increasing."

He proposed, in the electro-motive force that he would employ to work through so long a circuit, the *induced* current, produced or obtained from an electro-magnet.

In explaining the form of such electro-mag nets as he would employ, and that must be understood entirely apart from the signalling system that we have described, Mr. Allan explains his views thus :—

"The peculiarity of the apparatus to produce an electro-motive force suitable in all respects for the requirements of an ocean telegraph [patented June, 1852], consists in the application [to the working of electric telegraphs] of induced electricity produced from the closed or blind electro-magnet, whereby, from a given quantitive battery, a much greater magnetic influence can be produced than by a bar or open magnet, and, consequently, greatly increased inductive effects are produced in the secondary coils. Further, by the application of an appara tus [patented November, 1850], by which means the primary current is reversed, and made alternative, the inductive effects produced in the secondary coils are still further increased in intensity, and rendered more equable and distinct than by a mere make and break of the primary current. Thus it is, by these combinations, an electric force is produced of maximum intensity, combined with minimum quantity, and in all respects that which is absolutely necessary and required for extended submarine circuits. Besides, as by these means of reversing the primary current, the inductive effects are not only more defined and equable in their action, but also alternative—it follows that by their being alternative, their action on the conducting wire is to discharge or get rid of the retarding effects that accrue from the retention of a portion of the previous electrical action. From the minimum of quantity and maximum of intensity that may, by extended arrangements, be put in motion by electro-magneto-electricity, there is little to contend with in very long lengths of submarine conductors—which, beyond a thousand miles, as at present constructed, are practically next thing to insurmountable with voltaic electricity; and as the electricity and the conductor may be made relative to each other, there is no reason to suppose that, so long as continuity can be maintained, any required distance may not be compassed by electricity so produced.

"The combination of electro-magnets, or electro-magnetic induction coils for this purpose, may be formed in squares or parallelograms—some with two joined at the ends by keepers, others with four, having the primary and secondary wires on each and all combined, each into one circuit respectively, or with the primaries only on one pair of cores, and the secondaries on the other."

The direct connection that evidently subsists between the early Morse, Allan, and Wheatstone's line and dot systems, has induced us to group them together, so that the general reader should not have his attention divided by the introduction of systems. We shall next advert to plans proposed antecedent to those just described, and dependent on entirely different conditions for their practical operation.

Electro-Chemical Printing Telegraphs.—Many forms of telegraphic and analogous instruments have been proposed, in which the chemical powers of effecting decomposition of saline matter have been employed, to indicate messages that are to be sent. Before describing special forms of such apparatus, we may suggest a few simple experiments, by which the general principle of some of them will be elucidated and illustrated.

If a glass vessel, as a tumbler, for example, be divided into two equal parts by placing a card vertically and centrally inside of it, in the manner indicated in the annexed cut, and the vessel be then filled with a dilute solution of sulphate of soda, coloured by a little tincture or infusion of litmus, the liquid will only present a bluish-purple tint, due to the presence of the litmus. But if the wires from one or two voltaic cells be placed one each in the divisions, decomposition of the saline solution will be immediately effected. One of the solutions will retain its blue colour, whilst the other will become of a bright red. Now these results are due to the disengagement of the alkali soda in that division which remains blue, and to the liberation of the sulphuric acid in that which has turned red; consequently a portion of the salt has undergone decomposition.

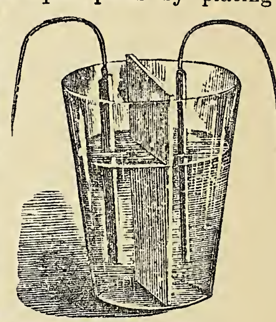


Fig. 275.

Applying the same principle in a different form, such an action may be taken advantage of for printing-telegraphs. For example: if a piece of thin calico be soaked in a dilute solution of sulphate of soda and ferrocyanide of potassium (the yellow prussiate of potass of com-

merce), squeezed by the hand so that all superfluous moisture is got rid of, and the cloth be then spread over and pressed on a sheet of tin-foil, no effect will result, because the salts are neutral, and have no action on the tin. But if the foil be connected with one wire of a voltaic cell, whilst the other wire is attached to an iron or steel needle, and the latter be drawn over and pressed on the cloth, a blue line or mark will be produced, because the chemical action engendered by the battery causes the sulphate of soda to become decomposed. Its sulphuric acid attacks and dissolves the iron forming the sulphate of that metal, which, coming in contact with the ferrocyanide of potassium, is, in its turn, decomposed, forming the well-known blue pigment called Prussian blue, and producing the coloured mark just referred to. This, therefore, shows that the electro-chemical action of a voltaic current may be put to telegraphic purposes.

The usual mode of so using this action is to cause an iron point to press against a metallic cylinder covered with cloth, moistened in the way already mentioned. The iron point is connected with one plate of the battery, whilst the cylinder is connected with the other plate. But, of course, only a blue mark or dot could be thus produced; but if the cylinder is caused to rotate on its axis, the dot will become a continuous line so long as the current passes, ceasing to be produced on the current ceasing.

To familiarise the mind of our readers with the principal mechanical part of such printing apparatus, we will suppose that a pianoforte key, made of metal, and with one of its ends attached to the wire of the copper plate of a voltaic battery, is so arranged, as that, when pressed down, it shall enter a small cup containing mercury. From this cup we will suppose a wire to extend to a needle, placed so as to rest with its point against a metal roller covered with cloth, which has been impregnated with the prussiate of potass; and that the roller is connected with another wire proceeding from the zinc plate of the voltaic battery. It is evident, that when the pianoforte key is pressed into the mercury cup, a circuit will be established; a current will pass; and the point of the needle will instantly impress a blue dot on the cloth—thus, . If, however, the roller be gently moved, then, instead of a dot, a dash ——, or long line ————, will be produced; the length depending on the length of time the key is kept pressed down, so as to continue the passage of the current. The instant the key is removed from the mercury cup, the current will cease to pass, and no effect will be produced on the distant roller. Now, this is exactly what happens in most of the chemical printing telegraphs: but we may be better understood if we refer to the following engraving, which affords an illustration of the most essential part of the apparatus.

In Fig. 276, we have *a* representing the roller on which the prepared cloth is wound; *b* is the needle which imprints a dot, dash, or line; c is a binding-screw, to which is attached a wire, *w*, extending to the copper plate of the battery, *h*. A wire is attached to the zinc of the battery, and reaches to a small peg, *g*; *f* is a key, which, when pressed down on *g*, completes the circuit. The current will then travel from the battery by the wire, *w*, to the needle, and thence by the roller to the wire, *w′*; returning again, through the key arrangement, to the zinc of the battery. Of course, no mark is made on the roller, except when the key, *f*, is brought

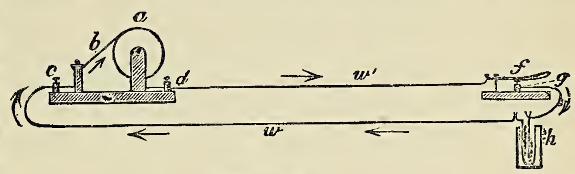


Fig. 276.

into contact with the peg, *g*. The roller, *a*, is gently turned by clock-work; or by hand, if for elementary experiments.

We have entirely avoided all mechanism used in the complete apparatus, so that our readers might gather a general knowledge of the *modus operandi.*

Hence a system, or code of signals, may be effected by making any gradation of length, from a dot to a line, the length of the latter depending on the length of time that the current passes in producing each signal.

Now it is evident that such telegraphs may be kept at work without necessarily requiring the constant attention of the telegraphist receiving the message; and not only so, the message itself is printed permanently by the transmitter—a circumstance highly favourable to accuracy of transmission, and avoiding risks that the telegraphic companies run of errors in the sending and receiving a message.

The early forms of such instruments were defective in many material respects, whilst those of more recent construction have, in certain cases, become of great practical use. But before entering into detail in respect to these, we will briefly describe an ingenious invention effected by Mr. Whitehouse, at one time electrician to the Atlantic Telegraph Company, in connection with the early, but, unfortunately, unsuccessful, attempt to lay a cable across the Atlantic.

Mr. Whitehouse's apparatus, to which we now refer, was intended to print music as quickly as it was composed, and was especially suitable for use in connection with a piano, or other keyed instrument. Beneath each key was a wire that was continued to another apparatus much resembling that already illustrated above by Fig. 276. The terminal of each of these wires was an iron or steel point, that pressed on some cloth moistened with sulphate of soda and prussiate of potass, the cloth being wound round a metallic cylinder in the manner already explained, and the cylinder being kept in continuous rotation. The iron points, of course, corresponded to the number of the keys in the piano.

Now, on the keys of the latter being pressed

down in the act of playing, contact was made between a battery and the apparatus just described, a current passing by each of the wires of the keys. So long as the finger pressed a key, the corresponding wires printed a mark on the cloth over the cylinder, the length of the mark depending on the time that the key was pressed down; and, consequently, not only were the notes printed on the cloth, but the length of each was also denoted. On completing the piece, it was only required to take the printed cloth off the cylinder; and as it was divided into two sets of lines—bass and treble—it might be easily played from, just as if it had been an ordinarily printed sheet of music; or the lines, &c., could be translated into the ordinary musical notation, and lithographed for publication.

We have frequently used the instrument with complete success, for dance and more sober music, and have also seen some excellent performers thus register and print their own compositions. The chief difficulty that occurs in making such an invention generally applicable is, that the cylinder requires to rotate very equably—a matter that is not easily attained. The same difficulty, as we shall subsequently see, hindered the early progress of all kinds of chemical telegraphs.

Mr. Bain was amongst the earliest, if not quite the first, to adopt such means in making an electrical telegraph. Faraday states that, in 1853, he employed Bain's printing instrument in the study of the inductive effect arising in submarine cables, described, in connection with researches into that interesting subject, at p. 510, *ante*. Bain was also the first to invent a type-printing telegraph, which is described in this work at another page.

In his electro-chemical printing telegraph, Mr. Bain employed paper or cloth prepared with the prussiate of potash, &c., as already described. The principal points, both chemical and mechanical, have been already explained, and the latter illustrated by the preceding cut (Fig. 276).

On such an instrument Dr. Lardner remarks—"An extremely feeble current is sufficient to produce the effect; but it will be necessary, when the strength of the current is very much reduced, to move the pen more slowly [or the roller], so as to give the time necessary for the weakened current to produce decomposition." On this point we may add, that we have seen such a telegraph working through an interval of 900 miles of coiled fine copper wire, without being able to perceive any such objection as Dr. Lardner suggests, although, of course, theoretically, he is quite correct. He adds—

"In short, a relation exists between the greatest speed of the pen, which is capable of leaving a mark, and the strength of the current; the stronger the current the more rapidly may the pen be moved. In this manner any kind of writing may be inscribed upon the paper [see the following account of Bakewell's copying telegraph], and there is no limit to the celerity with which the characters may be written, save the dexterity of the agent who moves the pen, and the sufficiency of the current to produce the decomposition of the solution in the time which the pen takes to move over a given space of paper."

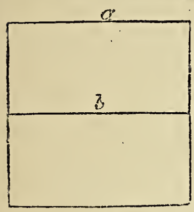
The code of signals first adopted for such arrangements was that of dashes or lines of different lengths, as already explained, and somewhat like those also adopted by Morse and others, although the latter produce similar signals by different methods, as have already been, or will be, explained.

Bakewell's Copying Telegraph.—A most ingenious invention was made in the early days of electro-telegraphy, by means of which the handwriting of the sender of a message could, under carefully-arranged circumstances, be exactly reproduced at any moderately distant station from that at which the message was forwarded. The inventor of this method was Mr. Bakewell, whose reputation as an electrician is well known. He called it a *copying telegraph.* And it is a most ingenious application of electricity; for, of all the wonders that these forces have called out fully, the transmission of the hand-writing of any individual from one station to another is amongst the most marvellous.

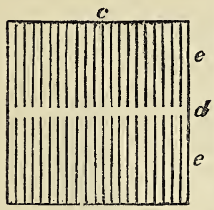
The secret of this process lies in so arranging a conductor with a partial non-conducting surface, that, by means of the latter, the current of electricity may be intercepted; and this is managed after the following manner:—The message is first written, by means of a weak spirituous varnish, on a sheet of tinfoil, and it is then dried. It is evident, that if a wire, connected with one plate of a voltaic cell, be drawn over the foil prepared in this manner, whilst the wire from the other plate is attached to the foil, the current will be complete so long as each wire is in contact with the foil; and it will be broken as soon as the wire passing over the foil touches the varnished surface, because such is, of course, a non-conductor. Now, if the tinfoil be connected, by means of a wire, with such an instrument as we have described in a previous page, in connection with electro-printing telegraphs (see p. 525, *ante*), so that it may be electrically connected with the needle, and one wire of the battery be in contact with the roller of that apparatus—the wire from the other plate being passed over the written tinfoil surface—no mark will be made on the prepared cloth when the battery wire comes in contact with the varnish; but whenever it touches the tinfoil, a blue mark will be printed on the cloth. If the needle, instead of being stationary, be allowed to traverse from one side of the roller to the other, whilst the roller itself is quickly moved round by clock-work, the continuous straight lines will be printed when the circuit is completed; which, however, will be interspersed with white spaces whenever the circuit is broken by the interposition of the varnished surface. Supposing the varnished surface to be a straight line across the tinfoil, then the printed copy would present a number of blue lines, crossed by a white one—as shown in the following diagram.

No. 1, in Fig. 277, represents the tinfoil sheet, *a*, from which the signal is transmitted, crossed

by the varnished line, *b*, which is the non-conductor; No. 2, *c*, is the cloth on which the signal is received and printed; *d* being the white space, unmarked with lines, and corres-



No. 1.



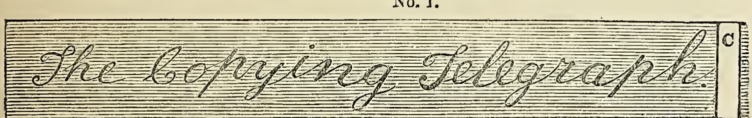
No. 2.

Fig. 277.

ponding to the varnished surface of the tinfoil plate; and *e e* are the blue lines printed by the traversing needle, which receives the electric current from the foil. No. 2, in fact, gives a representation of the cloth as it appears when taken off the rollers.

Now, the principle being established, it does not matter whether the line on the foil be straight, curved, or of any form; hence, if such be ordinary writing, that would be copied on to the cloth in an exact fac-simile of the original, just as we observe in the copy shown in No. 2. This is just the plan adopted, and the result

No. 1.



No. 2.

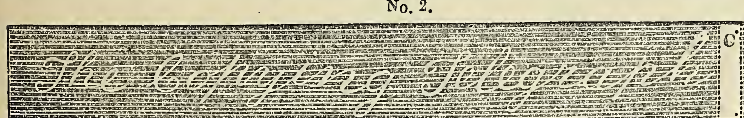


Fig. 278.—Bakewell's Copying Telegraph.

arrived at, by Mr. Bakewell's arrangement, provided that certain mechanical details are observed, to which we shall presently allude. The above diagram shows the appearance of the original, and printed, copy of a message, as illustrated by Mr. Bakewell, in his work on the subject.

No. 1, Fig. 278, represents the original, with the letters in black on the tinfoil; and No. 2 is the printed copy, having the letters in white intercepting the lines produced by the needle. Our readers will thus perceive, that by this plan, an exact copy of the hand-writing of any person may be transmitted by telegraph—a fact that makes Mr. Bakewell's invention rank very high as an instance of inventive genius. But, unfortunately, there is a very serious drawback to its utility, which is owing to the necessity that exists for both the transmitting and receiving-rollers to move at the same speed and at the same moment; and, consequently, through equal spaces in the same period of time. To effect this, Mr. Bakewell introduced regulating apparatus, worked by an electro-magnet, so that one roller could only proceed at the same rate as the other. In fact, in such an arrangement, the magnet acts in a similar manner to the pendulum of a clock. It is well known, that the weight or spring of a clock would quickly "run down" were it not for the action which a pendulum exerts on the seconds, or first wheel. A pendulum, thirty-nine inches long, beats about once in a second of time; and the spring of the clock is only required to keep up that motion. But two pendula never beat exactly together: thus they would not be effective as regulating arrangements in Mr. Bakewell's apparatus. Hence the employment of the electro-magnets, which necessarily act together, because their motion is mutually dependent. We are precluded from illustrating the mechanical parts which have been adopted; and this is not of so much consequence, because, although the invention is highly ingenious, it has scarcely ever been practically employed to any extent. Besides the difficulty to which we have alluded, there are others which also interfere with the result;—the receiving cloth may be unequally stretched; the two instruments may not commence work together, &c. Messages, however, have been sent accurately through a distance of fifty miles; and as many as 300 letters per minute can be printed by this interesting instrument.

Bain's Electro-Magnetic Printing Telegraph.—Mr. Bain's name has already been frequently mentioned in the preceding pages. He was one of the earliest inventors of electrical clocks, the electro-chemical printing telegraph, and other forms of apparatus depending on the voltaic current. In fact, he and Mr. Sturgeon may be considered as the pioneers of a great majority of the different forms of electro-magnetic and telegraphic apparatus that have been invented, adopted, or rejected for the last twenty-five years. Amongst other of his numerous inventions was that of the electro-magnetic printing telegraph, which we first saw at work about, as near as memory serves, in the years 1852—'54, at the Polytechnic Institution, Regent-street, London.

We have already remarked on the necessity of a skilled eye to read the signals of the needle and other instruments; but, by Mr. Bain's arrangement, it was proposed to print them legibly in type, as is now largely and perfectly done by various machines, and with especial success.

So many years have elapsed since this invention of Mr. Bain first appeared, that it seems as if it and the inventor have been entirely forgotten. In recent years, however, its principles have been successfully employed in other forms, as above mentioned. But, practically speaking, so far as this country is concerned, the plan has never been in even partial use. We believe

that it has been, and is still, in use in some parts of the United States. The specimens we have seen were beautifully clear and legible, and, in fact, exactly resembled the printed matter in a book, etc.

In order that the letters printed by the apparatus may be distinct and legible, two thicknesses of riband, saturated with printing-ink and dried, are supported by two rollers (not shown) so as to interpose between the type-wheel and cylinder. If a second copy of the message—which, it must be observed, is simultaneously printed at both stations—be desired at either, a slip of white paper is placed between the ribands to receive the imprint at the same time as the cylinder. The signals, it may be remarked, may either be symbols agreed upon, and reduced to a code, such as those employed with Messrs. Cooke and Wheatstone's electric telegraph, or the communication may be transmitted in words at full length.

This arrangement, although beautifully ingenious, and effective on the small scale, often failed in practice. Indeed, at the lecture-table we have seen this occur; and, consequently, although shortly after its invention it was the subject of considerable use, it was afterwards substituted by less complicated arrangements. Many of the inventors of the latter, however, were indebted to Mr. Bain for the first steps of the progress; but, as is commonly the case, we kick down the stool on which we stood, and refuse to acknowledge the source of our best successes.

Alphabetical Telegraphs.—The greater proportion of telegraphic instruments employed in public use, whether of the needle, electro-printing, Morse or most other systems, work by indicating or registering signals. Consequently, a skilled eye is required to translate such signals, whether they be indicated by deflection of a needle, by dots and dashes in the system of Morse, Allan, and others, or by the various forms of electro-printing apparatus that have been invented.

But for private use, as in houses, offices, or manufactories, a means of communication is desirable, that shall instantly exhibit to the eye, by spelling letter after letter, what is intended to be conveyed by the message. In other words, the receiver shall not perceive a signal indicating a letter, such as are represented as adopted in the needle telegraph (shown at p. 518, *ante*), but really see the letter itself; and by putting these together as transmitted, words are readily formed. We shall select a few of such instruments, most of which have been, or are now, in constant use.

Froment's Alphabetical Telegraph.—In the following cut, this invention, brought out about twenty-five years ago, is fully represented. In the front of the arrangement will be noticed a number of keys, to the extent of twenty-eight, arranged like the keys of a piano, and marked one at one end with a cross, and one at the other end with an arrow. The intermediate keys correspond to the twenty-six letters of the alphabet, each of which has a separate signal, commencing with A on the left, one key being devoted to one letter.

Over this part of the arrangement is a dial; and when any key representing a letter is pressed down, a current is established, which causes the

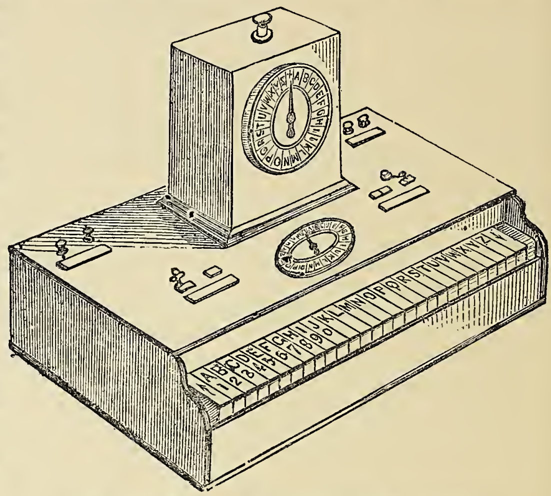


Fig. 279.—Froment's Alphabetical Telegraph.

mechanism of the dial to move in such a manner that the same letter is indicated on it, and also on another dial at a distant station.

In a modified form this instrument of Froment's was anticipated many years ago; but the arrangement then proposed was defective, for many reasons that need not be pointed out; for to register or describe all the failures that have been met with in electric telegraph instruments would by no means be a labour of love, except to patent agents, who would fondly remember their gains got at the expense of luckless inventors. Generally, however, all our modern improvements have been based on such failures, the originators having dug up the ground, whilst the improvers have sowed and reaped thereon. But to continue our description of Froment's apparatus. The arrangement essentially consists of two parts—the manipulator and the receiver. Of course, at both the transmitting and distant stations, precisely the same form of complete instrument is employed; but for our purpose we shall only consider the transmission part of the apparatus of the one station, and the receiving at the distant station.

The mechanism of the manipulation consists of a circular dial, on which the letters are printed; an index to point to the letters marked on the circular rim of the dial; and machine work that actuates the dial as each key is pressed down, and a current is thereby made to pass. The current, on entering the manipulator, passes to a spring that comes in contact with a tooth-wheel, on the opposite side of which is another spring connected with the wire intended to transmit the message.

The receiving instrument at the distant station is also a circular disc, with letters

marked on the rim, and corresponding with the rim of letters in the manipulator, or sending instrument. But in the receiver is an electro-magnet that is instantly set in action as the current is received from the transmitting manipulator—that is, the instrument *sending* the message. By means of various mechanical arrangements combined with the alternate action of the electro-magnet, the index is successively pulsated so as to indicate any letters of the message sent. In fact, the action on the receiving disc exactly resembles that of the second's hand of a watch. As the hand points out to each successive division on the dial of the watch, so the index of the receiving instrument indicates each letter in rotation; and when the index arrives at that which is intended to be there indicated, it is stopped for a moment to show that the letter is part of the message.

Of course, in the full run of the index round the disc contact is made and broken once for each letter passed, so that the depression of each key on the sending instrument, makes contact with the toothed wheel of its manipulator, and consequently with that of the distant receiver. The action will be easily understood if the unpractised reader inspects for a moment the motion of the escapement-wheel of a clock moved by a pendulum. In a series of such instruments, say at different stations, by means of a very simple arrangement, this is effected by the dial that will be seen immediately over the keys (as shown in Fig. 279, *ante*), and laying horizontally on the frame beneath the vertical dial or indicator; it also verifies the message sent, as its index, if the signal was properly transmitted, always points to the letter last signalled. An alarum is rung, by a separate electro-magnet, on the instruments at each station.

Wheatstone's Private Telegraph Apparatus.—This apparatus, invented by Sir Charles Wheatstone, and brought into extensive use some years ago by the District Telegraph Company in the metropolis, is of a similar nature to that just described, but differs in certain particulars. This arrangement was adopted for use in warehouses, or between places belonging to the same firm, but having, say the manufactory and counting-house, or warehouse, a mile or more apart. A bundle of wires is suspended overhead, at the house-tops, and carried to all parts of the metropolis. Each firm has its own wire. We will take for example a firm whose place of business is in Holloway, and the counting-house in Cornhill: we are referring now to an actual case by way of illustration. One wire connects the two places electrically together, and is selected, for the use of the firm, out of the rope of wires traversing overhead from street to street. The instruments are twofold. One is called the *communicator* (Fig. 280), in the following cuts, and is that which transmits the message. On its rim are printed each letter of the alphabet, and the numerals. The exterior of the *indicator* (Fig. 281) presents a similar appearance. As in Froment's Telegraph, the letters are pointed to by an index; and from them the message is gradually spelt out by the successive movement of the index over the dial, and its temporary stoppage at the indicator. The earth is used for the return current, and consequently, as just stated, only one wire is required by each firm, although in the open air

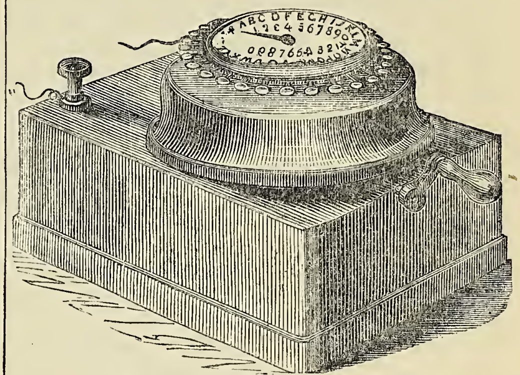


Fig. 280.—The Communicator.

many are bound together in a kind of electrical wire-rope. Hence, over the houses and chimneys in London, an immense amount of business is constantly being transacted between master and men, unknown to the unthinking passenger in the streets beneath.

This overhead system of town intercommunication by electricity was not established without encountering many difficulties. In the first place, many occupants of the houses were by no means satisfied that considerable danger might not result from their having poles erected on the house-tops—a suspicion since countenanced by many circumstances. Others had a foolish or superstitious dread of the electrical fluid passing over their heads. Some, again, knowing

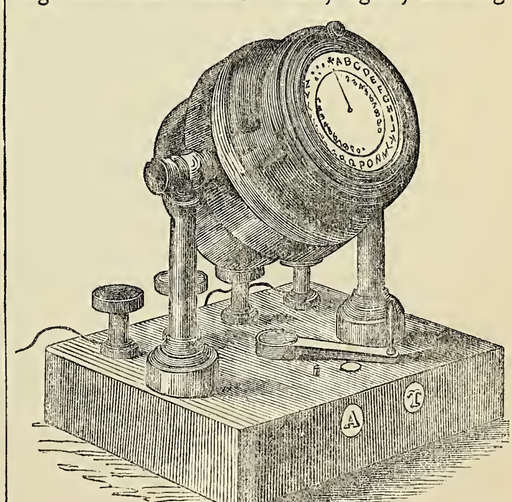


Fig. 281.—The Indicator.

that the company were compelled to adopt such a means of suspending or conveying their wires, persistently refused compliance until in some way they were remunerated. Objections were

also made on the score of injury to carpets, &c., by the men going so frequently inside to the top of the house; which, however, in the case of one pugnacious individual, was overcome by the workmen entering into a promise that they would only ascend and descend once through the house. They kept to their word by eating, drinking, and, we believe, sleeping on the roof, till the work in the particular case was completed.

Telegraphy by Sound.—Any of our readers who may have visited a telegraphic station, and have been admitted to the back scenes of the establishment, cannot but have noticed that a certain speciality exists in the mode of communicating messages in any form of indicating signals. Some transmitters are quicker than others; but not only so, there is a distinctive character that corresponds to that of the individual sending the message.

Precisely the same thing is noticed in an observatory, in reference to the observance and registration of astronomical phenomena. It frequently happens that two observers will not give the same "time" of the occurrence of the same phenomenon. The amount of this difference, which is termed "personal equation," varies from two-tenths to half a second of time; though instances have been known of this quantity exceeding one second of time. Dr. Maskelyne, and Kinnebrook, his assistant, differed in this manner seven-tenths of a second. In modern times, Bessel and Argelander have differed upwards of a second.

Precisely the same difference occurs in the appreciation or reading of telegraph signals; and this, doubtless, arises from the varying activity of the optic or aural nerves of the operators.

But we can give a still further and more popular illustration of such personality, whether as regards the eye or ear, by referring to the varying power of sounds of a musical character on different individuals. Some can instantly translate the sound, if we may so say, to a correspondence of their own ideas with those of the player on an instrument, or of a composer of the piece; whilst others are absolutely incapable of such appreciation, either of harmony or melody. It is related of Dr. Johnson, that being present at a concert when an elaborate piece of music was in course of performance, a friend remarked to him that a certain passage was difficult; to which he replied, "I wish it were impossible."

At p. 519, *ante*, we have already remarked on the diversity of general talent in respect to telegraphists; but we may here especially call attention to the translation of the message by sound: and are indebted to Dr. Lardner's work for the following remarks on the subject:—

"The celerity of transmission attainable with the Morse telegraph [see *ante*, p. 520]—which, of all forms of telegraphic apparatus hitherto invented, is that most extensively used—is very considerable, but varies, perhaps, still more than the needle instruments, with the skill of the telegraphist.

"In this instrument, it will be remembered that the transmitting agent plays upon a key commutator, the letters being severally expressed by repeated touches of the key, succeeding each other after longer and shorter intervals.

"At the station receiving the despatch or message, the armature of the electro-magnet moves simultaneously with the transmitting key, and at each of its motions towards the magnet it produces a distinctly audible click. The receiving agent acquires, by practice, such expertness and quickness of ear, that by listening to this clicking he is able to interpret the despatch, and to write it down, or dictate it to a clerk, without using the apparatus for impressing it upon the paper ribbon.

"Different telegraphists acquire this power of oral interpretation of the despatches with different degrees of facility and precision; but all are, more or less, masters of it. So much so, that in most cases on the American lines, it is by the clicking of the magnet that the messages are taken down, being afterwards corrected, if necessary, by comparison with the indented paper ribbon.

"The telegraphist is placed at a table, upon which the instrument stands, having before him the paper upon which the message is to be written, and, at his left, a provision of black-lead pencils ready cut and pointed, usually half-a-dozen. When the transmission of the message commences, the electro-magnet dictates it to him, letter by letter, at the same time indenting it upon the paper ribbon. He writes it down; and, in general, it is delivered by the magnet as fast as he can write it, availing himself of all such abbreviations as are intelligible to those who may have to read it.

"As the points of the pencils are successively worn, he lays them on the table at his right hand. A person engaged exclusively in that process visits his table from time to time, repoints the pencils lying on his right, and replaces them on his left. This person passes round the telegraph office, from table to table, keeping up a constant supply of properly pointed pencils at the hand of each telegraphist.

"The most expert telegraphists are able to take down the message in this manner by ear, without any reference to the ribbon, and so correctly that there is no need of verification. When the message is concluded, the sheet on which it is written is handed to another clerk, who is provided with a stock of envelopes, in one of which he encloses it; and writing the address upon it, delivers it to a messenger, who forwards it to the party to whom it is addressed. Meanwhile, the paper ribbon, on which the message has been indented in the telegraph ciphers, is cut off, folded up, and preserved for reference.

"It is only, however, the most expert class of telegraphists that can operate in this way. Others, less able, are always obliged to verify and correct what they have taken down, by comparison with the indented ribbon after the message has been concluded; while others, less

able still, cannot trust themselves to take down by *ear*, and sit before the ribbon as it is discharged from the roller, writing out the message from it by the eye.

"The salaries allowed to different agents vary according to the skill they attain in their operations. One who acquires the power of taking down rapidly and correctly by ear, will receive twice the amount allowed to him who can take down by the eye, the latter being always slower than the former.

"It often happens that the power of interpreting easily and correctly by the *ear* is very important, as in the case in which the mechanism of the instrument for moving and indenting the paper may have been accidentally deranged and disabled, or in which the office may be deficient in its supply of paper ribbon."

The peculiarities of this ear mode of electro-telegraphy are still further explained, as adopted in America, in Colonel Shaffner's *Manual of Telegraphy.* The results are certainly entirely inversive of the maxim of the ancient Latin writer—that things submitted to the eye impress the mind more than those heard by the ear.

One of the most recent inventions in regard to telegraphy is that of using two bells, having two distinct tones. The bells are struck by clappers actuated by electro-magnets. This plan, however, has been but little used.

It is evident, however, that a peculiar, excited, or excitable condition of the aural nerves is essential in respect to such means of telegraphy. Just as the voices of human beings vary, by numerous gradations, from a low *bass* to a high or even shrill *treble*, so must, analogically, the power of appreciating sounds in telegraphy. But not only so : it is evident, that as such a method is one of, comparatively speaking, only recent development, the circumstances and requirements of telegraphy have called out new or enlarged power of man's nervous and muscular qualities. Truly, we live in days of great advance; the necessities of former days have given way to those of the present; the rapidity of our means of travelling, and telegraphic intercommunication, have forced on us new conditions; and the elasticity of the human mind, and physical powers, have not been found wanting to satisfy the newly-imposed conditions on them.

Of course, all forms of alphabetical telegraphs (already described) are much slower in their indications than such as are afforded by any form of the signal indicating instruments. But the former are intended for the use of persons who are, or may be, in many cases quite incapable of the dexterity that a regularly educated telegraphist possesses. In all branches of applied art or science, we find that great diversity of power or ability exists in individuals with respect to these powers of action. Fortunately, therefore, the skill of electricians and electrical engineers has placed in the hands of all, methods of availing themselves of electrical communication. By means of the alphabetical or printing telegraph, the clerks of the counting-house, and the operatives of the factory, a mile or more off, may be able, slowly but surely, to interchange wishes; whilst on our railways, and in the offices of our telegraphic companies, to whom speed of transmission and reception of a message is a condition of success, a much quicker mode of operation becomes absolutely necessary, and is, consequently, practised as a rule or habit.

The most remarkable instances, at the present day, afforded in regard to speed of telegraphy, are those in connection with parliamentary reports, and, frequently, speeches by eminent men at provincial meetings. This is a subject that will be fully dealt with under the head of the British Postal-Telegraph system.

We have already referred, generally, to the method of pneumatic pressure for conveying messages through short distances, stating that—

"Many years ago, Mr. Latimer Clark prepared and fixed a 'small bore' pneumatic tube between the Electric Telegraph Company's station in Lothbury, and the Stock Exchange, worked by a small $1\frac{1}{2}$-horse engine. The messages being only sent in one direction, a vacuum only was used. The system was subsequently extended to Cornhill, Mincing Lane, etc., and proved of great value. Some dozen years after Mr. Clark's ideas were carried out, the same thing was 'discovered' in France by Messrs. Mignon and Ronart. It is wondrously easy to 'improve' on anything after it has once been invented, and consequently we find the above gentlemen have made some excellent improvements. They use wrought-iron pipes of about the same diameter as Mr. Clark's leaden ones, interiorly glazed, and connected by union joints made air-tight by india-rubber. The message carriers are either of leather or metal, made short to take sharp curves easily. The pipes are buried beneath the surface, just as gas or water-pipes are laid. Messrs. Mignon and Ronart avoid the drawbacks of the English system as follows :—They make use of a barometer of water to produce a vacuum, and the pressure of the ordinary water-pipes to produce compression. At each station is a cylinder, the volume of which is double that of the pneumatic tube communicating to the next station. Communication between cylinder and tube being closed, the water is admitted into the cylinder until it is half filled, and thus, the air being compressed into half its volume, pressure is produced to drive the carrier speedily to the other end of the tube."

In 1881 the plan of sending telegrams to different parts of London by the pneumatic system, had largely developed between the head office in St. Martin's-le-grand and the district and sub-district offices within about a mile distant. At the head office, powerful steam machinery and air-pumps with condensers had been erected, and the arrangement permitted of a hundred or more telegrams being sent, at the rate of a mile per minute, to the district offices, thus saving the time which would have been absorbed by the ordinary telegraph transmission by instruments. This method is not only a saving of time, but of expenses, and will no doubt be largely extended.

The results of the working of Professor Sir Charles Wheatstone's cryptograph promised to be very valuable, as some such instrument appeared to be a great desideratum in military telegraphs. In the cryptograph are two circles of alphabets, one of which is set as a key to the other, which key can be varied day by day, or even message by message, and in this way can only be intelligible to those for whom it is intended, and who are previously informed of the arrangement to be used. The message, by this means, could neither be known at the telegraph stations by transmitter or receiver.

Recent Improvements in Telegraphic Indicating Instruments.—To notice all the improvements that have been effected in respect to instruments employed for indicating purposes in electro-telegraphy during the last twenty years, would be impossible to do in this volume.

The foundation, if we may so say, of all telegraphic apparatus, lays entirely in the magnetic and electric affections of wires conducting the electric current in the one case; of pieces of steel possessing permanent magnetism; and of soft iron, converted into an electro-magnet by a current of voltaic electricity; excepting, for the present, those applications of electricity in which its chemical powers are brought into action, as in Bain's and Bakewell's electro-chemical printing telegraph, already described at pp. 525, 526, *ante.*

Motion effected by electro-magnetic induction, to set in action arrangements by means of which type can be made to print a message; or, as in Morse, Allan's, and Wheatstone's arrangements, dots and dashes are employed as signals; deflections of a magnetic needle, as in Cooke and Wheatstone's single and double-needle instrument, have been generally the plans most patronised in recent years for telegraphic purposes. The elementary principles of all such instruments have been already described; as have also those of the alphabetical instruments of Froment, and that of Wheatstone, intended for local or distinct purposes.

All recent improvements of telegraphic apparatus have had special objects in view. If for public use—that is, to accommodate the wants of commerce and society at large—such improvements have been generally confined to the progression of rapidity of communication between each station. If for private use, the object has been to do away with what we may properly call skilled telegraphic labour, and to substitute for it certain methods, by means of which, the clerks in a counting-house become quickly efficient in communicating despatches between the office and a warehouse, or a manufactory.

The public exhibitions that have been held in the leading capitals of Europe, during the last twenty years, have largely tended to a diffusion of a knowledge, and the adoption of new forms of telegraphic apparatus. In that of London, in 1862, and of Paris in 1881, many eminent names, in respect to electro-telegraphy, will be remembered. Taking the British department (1862), we notice the following:—Mr. Allan, of the Adelphi (whose cables, and their proposed methods of signalling, have already been described at p. 522, *et seq.*) Another celebrated name in electro-telegraphy (Brett) also appears in the list of exhibitors; and the British and Irish Magnetic Telegraph Company (of which mention has already been made) was also amongst those who illustrated novel or valuable facts in telegraphy.

In respect to this company, Dr. Lardner, in his work on the electric telegraph, remarks that they, retaining needle indicators generally used in England (1854—'58), rejected the galvanic battery, and substituted the current induced by magnetism in its place. The instruments they at first adopted were those invented by Henley and Forster. Induction was effected by magneto-induction on soft iron; momentary currents were transmitted by the conducting wires; and these currents, by mechanical arrangements, were readily reversed.

As already stated at p. 520, *ante*, no great advantage arose from such arrangements. We have watched the use of such apparatus repeatedly at Dumfries, and at the former head station of the Magnetic Telegraph Company, and could not possibly see any special advantage arising from the adoption of magneto-electricity, except that of giving a name to a new company. Dr. Lardner, as stated at a previous page, thought otherwise; but since he wrote the opinion there expressed, electro-telegraphy has undergone as much improvement as we have seen to occur in steam navigation since he first expressed his opinion that Transatlantic steam voyages would never pay. The great principle first adopted by this company, was not that of the deflection of the magnetic needle by the passage of the current over it, as in the case of Cooke and Wheatstone's instrument (described at p. 518, *ante*); but by inducing magnetism in electro-magnets by aid of magneto-electricity, the magnetic needle was deflected by their attraction: hence the oscillations necessary to Wheatstone's instrument were avoided; in other words, the receiving clerk had not to wait until the oscillating needle came to rest; for in the magnetic instrument, its deflection was, or is, instantly followed, and necessarily, by a state of rest.

In the Exhibition of 1862, Glasse and Elliot, Henley, Hooper, Siemens, Halske, and Company, Silver and Company, the Submarine Telegraph Company, Tyer, the Universal Telegraph Company, working under Wheatstone's patent (described under the head of Alphabetical Telegraph, at a preceding page), C. F. Varley, C. V. Walker, Webbs and Hall, the Gutta-Percha Company, and many other firms, exhibited most ingenious instruments in connection with land and submarine telegraphy.

Tyer's arrangement consisted of a dial-face placed at each station, on which the needles were worked by electro-magnetic action. A bell and gong were also provided, for the purpose of calling the attention of the attendants at either station. The dial-face was divided into two parts, one for the up, and the other for the down line; and on the right and left of the face

of the dial, the words, "Train on the line," and "Line clear," were engraved. According to this system, each signal station communicates with the signal station on each side of it, so as to announce both the departure and approach of a train. The receiver of a signal cannot alter it; and a signal once sent remains fixed until the next signal is sent—an advantage of the greatest importance in such matters, because of the constant disputes that always arise in case an accident occurs through a real or supposed mistake of signals, or through an alleged non-showing or non-observance of them. By Tyer's system, the line of railway is divided, of course, into sections in respect to the trains by the signal stations; and no train is permitted to pass one of the stations until the signal has been received that the next station in advance is clear. The system, and its mechanical arrangements, are remarkably simple. In a modified form, such an arrangement has been adopted on some of the suburban lines; and the Metropolitan under-ground railway, with its branches, together with many other short lines terminating in many parts of the metropolis, would be absolutely impossible to work, unless such a system, called the "block," was in constant exercise. Perhaps the best testimony to the value of such methods, is the fact that scores of millions of persons have been conveyed on the Metropolitan Railway since its opening, by trains travelling at intervals of from three to five minutes, with rarely any serious accident to life or limb occurring that could be justly traced to railway mismanagement.

Several other peculiar applications of the electric telegraph—a modification of the system for special purposes—were the subjects of illustration at the period just named, in connection with, or consequent on, the Exhibition of 1862.

One that, in our opinion, was, or might be, of great value, may be instanced in *Siemens' Electric Resistance Thermometer*, the object of which was primarily to test the heating of submarine telegraph wires. At a previous page, it has been pointed out, that when a large quantity of gutta-percha cable, especially if coated with tarred or oiled hemp, is packed in a ship's hold, great danger exists of the gutta-percha being melted by the spontaneous heating of the exterior of the cable. It is well known that hemp, and many other vegeto-carbonaceous materials, if exposed to air and moisture, become heated, owing to the oxidation of the carbon of the materials. Hence a common cause of spontaneous combustion in cotton and hemp, or flax manufactories. It has also been pointed out, in our remarks on the peculiarities of Hooper's core, in respect to its employment in hot climates, that the latter is entirely free from such objections. As just noticed, Siemens' electric resistance thermometer was intended to detect such heating in submarine cables so packed in the holds of ships, or in such other circumstances as would be likely to produce similar results.

It is an adaptation of the laws of the resistance of conducting wires, already so fully and frequently explained in the preceding pages. The resistance is measured by means of an ordinary galvanometer. The plan is equally applicable to detect, in factories, warehouses, or any other places where large quantities of fibrous material are stored, a tendency towards spontaneous combustion.

Such an instrument would, of course, become of great value; and if its indications can be relied on (which surely should be the case), all interested in such matters would do well to inquire into its capabilities.

The apparatus consists of a differential galvanometer and of a bath of water (or oil), the temperature of which can be changed at will by opening one or the other of two cocks, the one bringing a supply of cold, and the other a supply of hot liquid, an overflow-pipe being provided to prevent accumulation. A battery of from four to eight cells is also provided, besides a number of electric coils, consisting each of a certain length of thin insulated platinum wire inclosed in a sealed metal tube.

These coils having been carefully adjusted, in the first instance, so as to offer equal resistance at one temperature, are connected to insulated copper leading wires of comparatively large sectional area (No. 16, B. W. G.), the ends of which are brought to the binding-screws of the apparatus, to be inserted, when required, into a circuit including the battery and the galvanometer. These "thermometer coils" are deposited at the places where the temperature is to be observed, excepting one, which has to be reserved for comparison with the others. This last-mentioned coil is, through its leading wires, so connected as to form an electric circuit with the battery and the second coil of the differential galvanometer, and is immersed in the bath before mentioned. It is evident, that if the temperature of the bath should be the same as that of the place where the thermometer coil under examination is deposited, the two electric currents proceeding from the battery will meet with equal resistance in the two circuits, and, in passing two spirals of the differential galvanometer in opposite directions, will produce no visible effect on the needle. If, however, the temperatures of thermometer and balancing coil should be unequal, the needle will be deflected by the preponderance of current in the cooler circuit, showing, by the direction of its deflection, whether cold or hot water should be added to the bath to establish equilibrium of currents. When this equilibrium is obtained, the temperature of the bath is observed by means of an ordinary mercury thermometer, which temperature must be identical with the temperature at the distant place.

In dividing the "thermometer coils" into two portions, the apparatus is rendered applicable for observing wider ranges of temperature than can be directly attained by the mercury thermometer; and in this modified form it may be used for pyrometrical purposes. In measuring ordinary temperatures, the employment of equal and undivided coils is, however, not only the most simple arrangement, but it has the

advantage in its favour, that the accuracy of the observation is not dependent upon the rate of variation if resistance be uniform, or even accurately determined. The heat produced in the coils by the electric currents employed, affecting the two coils equally, is also completely compensated in using equal coils.

Next in importance to the Exhibition in London, of 1862, was that at Paris in 1867. Generally speaking, telegraphy and electric apparatus were most abundantly represented. Amongst the displays of electrical apparatus, was conspicuous, and foremost, the name of Siemens, as familiar to us in England as that of our own Wheatstone. One brother in Berlin (Dr. Werner Siemens), and one in London (C. W. Siemens, F.R.S), have both taken places in the very foremost rank of telegraphic electricians ; whilst a third (F. Siemens) contributed the original model of those admirable regenerative furnaces, which Faraday thought a worthy subject to extol in one of his very latest lectures. The importance which electric telegraphy has taken amongst modern institutions, is a very substantial reason for reviewing a collection of such importance as this assumed in the Prussian court. M. Vogel, of Berlin, showed some capital specimens of covered wires for galvanometers, and wax-covered wires for house telegraph work. He adopted the highly convenient practice of giving, in his labels, the actual diameter of the wires in French millimetric measurement, in addition to their German numbers ; which simple plan not only prevented confusion and mistakes, but made the comparisons of the electrical values between German and French wires easy. Mr. Wilhelm Horn, of Berlin, was the maker of a capital specimen of direct ink-writer, which was, perhaps, better finished than any other instrument in the Prussian collection, and the construction of which was a praiseworthy copy of Siemens and Halske's polarised Morse combined with Digney's ink-roller. The price was 420 francs, which is certainly cheap, if the maker supplied all instruments for practical use of the same finish and the same price. Mr. Wilhelm Gwilt, of Berlin, had a Morse embossing instrument of very good finish, and used a very secure means of preventing dust getting into the interior, by placing a sliding-plate before the hole where the break-lever comes out. Bernhard Behrend, of Coeslin, showed some excellent discs of Morse paper ; and Levin, of Berlin, exhibited two of his new printing telegraphs, in which what is to be seen of the workmanship may be praised ; but the electric department was deficient, as it required two lines of wire between the instrument and the direct effect of the electro-magnet for printing, instead of using an intermediate clock-work, as is generally done, and by which he would have gained considerably in strength and cheapness. The arrangement of the alphabetical dial, in having forty squares for twenty-six letters, was rather impracticable, and characteristic of the general value of the instrument. M. Levin also exhibited some electric clocks, the success of which was doubtful.

The largest exhibitors were, as might be expected, Messrs. Siemens and Halske. One of the most remarkable of their instruments was their dynamo-electric apparatus, for the conversion of mechanical work into electric current. During 1866, Mr. Wilde, an electrician, of Manchester, published a description of a new arrangement he had made for producing electric light. This arrangement consisted of a large electro-magnet, between whose poles a Siemens' barrel-bobbin was rotated, the electro-magnet or soft iron cores being magnetised by means of a current produced by a Siemens' magneto-electric battery of permanent magnets. Soon after the publication of this idea by Wilde, and probably suggested by his paper, came propositions from Siemens and Wheatstone to make the apparatus magnetise itself by closing a circuit between the rotating coils and the wire of the fixed magnet. In January, Professor Magnus read a paper before the Academy of Sciences of Berlin, on the new Siemens' apparatus ; and in February, Professor Wheatstone read a paper before the Royal Society, both having independently come upon, and carried out, the like idea into practical results. Mr. Ladd (London) has since produced an improvement of these ideas, by placing two rotating bobbins, or Siemens' armatures, between the electro-magnets, one at each end. Recent improvements will be described in the next chapter on the Electric Light.

In respect to this machine (already, in part, described at a previous page), the following supplementary remarks may be of interest. They are extracted from a paper by Mr. Ladd, read at the British Association meeting of 1867. The author considered that "the most powerful magneto-electric machine hitherto constructed was that by Mr. Wilde, which received its charge from sixteen permanent steel magnets. Siemens and Wheatstone have since shown, that the residual magnetism left in soft iron after being under the influence of a battery or permanent steel magnets, can be augmented from the currents generated by itself, by merely applying dynamic force to the revolving armature containing a coil of copper wire, the terminals of which are connected with the wire surrounding the electro-magnet ; and, although great effects are produced, the current itself could only be made available by its partial or total disruption—in the former case diminishing the power of the electro-magnet, and in the latter reducing it to its normal condition. But in the machine the author had constructed, the power of the electro-magnet is kept up ; whilst a separate current, to be applied to any useful purpose, can be drawn off by means of an independent arrangement. It consists chiefly of two plates of iron ; to both ends of each is fixed a portion of a hollow cylinder; these plates are then placed at a certain distance apart, and insulated from each other in such a manner that the cylindrical pieces will form two hollow circular passages, into which spaces two Siemens' armatures are placed. The plates are surrounded by a quantity of stout copper wire, and connected together ; the two terminals are brought into connection with the commutator of

the smaller armature, so that each change of polarity in the armature will augment its magnetism. When the machine is first made, it is only requisite to pass a current from a small cell for an instant to give the iron polarity, and after this it will retain a sufficient amount of magnetism for all future work. If the armature in connection with the electro-magnet is made to rotate, there will be a very feeble current generated in it; this passing round the electro-magnet will increase the power with every additional impulse. It will thus be seen, that the only limit to the power of the machine is the rapidity with which the armature can be made to rotate, and which is entirely dependent on the amount of dynamic force employed. But the great improvement in this machine is the introduction of the second armature, which, although it takes off currents generated in its wire by the increased magnetism, does not at all interfere with the primary current. The machine shown in the Paris Exhibition measured about 24 inches in length, 12 inches in width, and about 7 inches high; but this one having been imperfectly constructed as to its proportions, the results obtained were, no doubt, much less than they would be with a better instrument. Notwithstanding, the author had found it would keep 50 inches of platinum wire, ·01-inch in diameter, incandescent; and when a small voltameter was placed in circuit with the second armature, it would give off 250 cubic centimetres of gas per minute; and, in connection with an electric regulator, would give a light equal to 35 Grove's or Bunsen's elements; the driving power expended being less than one horse. The author next described a machine, of which the first example is now constructed. It is on essentially the same principle as the last; but instead of having two independent armatures running in separate grooves, they are fixed end to end, so as to appear like one continuous armature, but so placed with reference to each other that their magnetic axes shall be at right angles. By this arrangement there is only one opening required for the armature, and full advantage of the horse-shoe form of magnet can be taken. The shoes of the electro-magnet are so proportioned to each other that there is a break in the magnetic circuit with reference to each armature alternately; but, by their disposition at right angles, there never is an actual break in the complete magnetic circuit, but simply a shifting occurs of the principal portion of the magnetic force from one armature to the other, at the precise moment required to produce the best effect. The mechanical advantages to be obtained by this disposition of parts must be at once obvious, as one pair of bearings, and one set of driving gear, required in the previous machine, are here dispensed with; and from the fixing of the two armatures together, the currents are made to follow perfectly isochronously with each other. It may, however, be found of advantage to vary the angle of position of the armatures with reference to each other, according to the speed at which they are driven, so that the current given off by the exciting armature may, at the precise moment, exert its full effect upon the electro-magnet, so as to produce the best effect on the second armature."

We next turn to consider some of the most important telegraphic arrangements of the Paris Exhibition. At a previous page we have noticed an application of the force of air, as a substitute, under certain circumstances, of the electric telegraph (see p. 531, *ante*, for description of Mr. Latimer Clark's arrangement). In short distances, under say a mile or so, it is quicker as well as easier to send the written message itself. But the main reason for the use of pneumatic tubes is, that the central office in communication with the telegraphs to all parts, not only of the city, but the world, is seldom the point of chief collection. For example, in any city the point of chief collection at particular hours is the Exchange; at others it may be some convenient station, from which newspaper telegrams are despatched, and so on. In Paris, at the Grand Hôtel and Louvre, there are collections as well as at the Bourse. The messages are, therefore, in some convenient manner, blown through a tube. In Berlin, for sending the actual messages in this way from the Post-office to the Exchange, an iron tube, $2\frac{1}{2}$ inches in diameter, is laid between these two points and back again, making a complete circle, the two ends of which, at the home station, are in connection with two large iron reservoirs, in one of which a vacuum of half an atmosphere ($7\frac{1}{2}$ pounds per square inch) is maintained, and in the other a pressure of an atmosphere and a-half (or $22\frac{1}{2}$ pounds per square inch) is kept up—the air being pumped continually out of one cylinder, or reservoir, into the other by a steam-engine, so that a continual current is kept up through the whole tube system or circle. By means of this continual current, suitable iron carriages, supported on four wheels, containing the written messages, are driven through the tube; these carriages are large enough to hold some twenty or thirty written messages, such as the forms usually provided at the ordinary electric telegraph stations. In sending the messages, one of these waggons is introduced into the carrying tube by means of a slot at the particular station transmitting. Each station has also its receiver. This is a tubular box, the interior of which is lined with bristles, like a brush; in this the waggon is arrested in its passage. A pedal lever arrangement, with a plunger, enables the operator to push the waggon out of this brush, the tubular box of which is interchangeable with a portion of the direct tubing when the waggons are passing through to other stations, the signals to the various operators being communicated by independent electric wire. As already stated at p. 531, *ante*, a system of pneumatic despatch, with felt carriages without wheels, on Mr. Latimer Clark's plan, had been in use for some five or six years by the Electric and International Telegraph Company, at the Telegraph Street, and other city stations in London. In the French system they used leather carriages,

and compress the air, not by steam, but by letting the Paris supply-water into a large cylinder about ten feet high, by five or six feet diameter. This was to be seen at work at the central station in Rue Grenelle, St. Germains, which communicates with the Louvre, the Grand Hôtel, the Exchange, and several other stations, the whole length of tube being eleven kilometres, extending over a large circle of the city. The cost of each despatch of a train of waggons, there being generally five in a set, is stated to be at the rate of 25 centimes, or twopence-halfpenny, for water-power per kilometre distance travelled over. The French assert that by this means they save considerably in porterage. This arrangement was made by M. Baron, inspector of French telegraphs.

The relative benefits of the three systems may be thus briefly stated. The Prussian telegraph direction has the decided advantages, when many despatches have to be sent, of greater speed, and of the tube being always ready for use, because the air is always circulating in it. The French system has the advantage on lines little used, as by it they do not consume fuel all day long, whether at work or not. By keeping up the constant current, the French consider the Prussians waste a considerable amount of power. The English system is a mean between the two ; the steam-engine pumps one reservoir full of air, a portion of which is blown off when wanted for despatch.

Messrs. Siemens and Halske showed a Morse embossing apparatus, with an American relay and vertical galvanometer, the workmanship of which was very good, and the apparatus very sensitive. Another most interesting portion of their exhibit was an entire railway system of Morse ink-writing apparatus, in which a continuous current is used instead of occasional currents of electricity, so that the writing is done by interruption instead of making the circuit. By this means only a single battery is necessary for a great number of stations ; and by separating the line at any point, the signals may be given to all the stations in circuit. In this way the guard of a train which has come to grief need only cut the wire, and, by inserting a pocket interrupter, can communicate with all the stations on the line. This system is used almost exclusively on the American lines. Every guard in America carries in his pocket a little sounding apparatus, or "sounder ;" so that, by cutting the lines, he has only to join the ends to his sounder, and he may either receive or transmit, the messages being read by ear and not by sight. One of these American sounders was shown by W. Bond and Sons, of Boston, United States, in the American Court ; it was contained in a sort of snuff-box case, its dimensions being about four inches long, by two broad and one deep. Another affair, shown by Siemens and Halske, was a bridge for testing cables. A commutator permits, by the changing of the places of the three contact stoppers between the slabs of the commutator, the alterations of the connections of the conductor, so that the resistance of the conductor by Wheatstone's bridge system, that of the insulation by three different systems, charge, discharge, electro-motive force, constancy of apparatus, and several other matters necessary in cable-testing work can be performed. All this is done with only two boxes of resistance coils. The galvanometer used with the system is on the differential construction ; the large bobbin exercising about 1,000 times the deflective force of the small one ; the small bobbin is vertical, and its distance from the needle may be adjusted in order to alter the relation between the deflective forces of the coils. The apparatus is so arranged that the resistances of insulation of the cable may be read off on a scale, showing at the same time the distance of the bobbin from the needle. There was also, on their stand, a type-transmitting telegraph with galvanic currents. In 1862 they showed a similar apparatus, worked with magneto-electric currents. The present one seems to be the perfection of an apparatus published by Professor Morse in 1835, but given up by him on account of mechanical difficulties he could not surmount. The system consists in metal types passing under the end of a lever, which is lifted and let fall by the prominences and depression of the types, giving thereby the necessary currents to the Morse machine at the receiving stations. With this apparatus was shown a machine for composing the types, for sending the messages, and another for distributing them. A very interesting arrangement was exhibited for measuring the height of water in a reservoir by means of electricity. A wooden float swims on the surface of the water, and to it is attached a pitch chain, passing over the teeth of a cog-wheel, and carrying at its other end a counter-weight. When the water either falls or rises, it turns the wheel one way or the other, giving either positive or negative magneto-electric currents, which traverse the telegraph lines—one for the positive, the other for the negative results. These lines end in two electro-magnets, whose armatures give either backward or forward motion to the indicator stationed—say, for example, in the office of the engineer, or elsewhere as may be desired. Siemens and Halske also exhibited an improvement on the electro-magnetic dial, such as were extensively used by the London Fire Brigade. The improvement consists in combining the indicator and transmission dials. The apparatus was shown in operation, and worked admirably ; only, in outward appearance, it reminded one of the continental champagne coolers, having a little too much plain polished white metal surface without any relief.

The Prussian Telegraph Direction showed two telegraph lines with different kinds of connection and Prussian insulators. They also exhibited two insulators, invented by Colonel Chauvin, for attaching to living trees. It would be an excellent system if the trees would only grow conveniently along the routes of the telegraph lines ; but, unfortunately, telegraph routes commonly go through treeless regions ; and where trees exist, they are never, or rarely,

exactly where they are wanted. The form of the bracket is that of an iron horizontal ⊳ driven into the tree, from which the insulator swings, to allow of the rocking of the trees without injury to the wire. They further showed specimens of their under-ground and submarine cables, made for them by Messrs. Felton and Guilleaume, of Cologne, upon a core of the Wharf Road Gutta-Percha Company, of London.

In the British Court, Wheatstone did not exhibit. He was one of the jurors; and, therefore, declined to show. His latest improvements in telegraphy have been already described at a previous page. One of the most important novelties shown was Donald Nicoll's system of under-ground telegraph. His plan is first to imbed his hemp-covered copper wires in asphalte, in open-topped, square iron troughs, of eleven or twenty-two feet lengths. In going through ordinary rural districts a furrow is run by a subsoil plough, and the lengths simply laid in, joined together with asphalte, and covered over. In wild countries the like can be inexpensively done. Once buried, the line can only be found by those who have the key; and it is, consequently, far more safe from wanton or malicious injury than post lines; and, moreover, these subterranean lines are not exposed to the same damaging atmospheric influences, whilst the asphalte with which they are protected is next to imperishable. The subterranean line is only exposed to mechanical injury, such as land-slips or other disturbances of the ground, which are always of very rare occurrence, and which, when they do occur, can be traced up to by electrical testing. Any capable electrical engineer can always determine the fault to within 1 per cent.; that is, within a mile in a hundred miles, within a foot in a hundred feet, and within a hundredth part in a foot. A considerable specimen was partly laid, and partly exposed, along the railway beneath Stephenson's locomotive engines. The advantages offered by this system are really of the very highest value. The insulation of the wire is next to perfect; or, indeed, we should rather say, as perfect as possible; the wires are well preserved, and their safety as great as can possibly be; repairs are very easy; a larger number of wires can be laid within the same space, and at a far less cost than by any other system; sections may be made of any length convenient for transport, and a whole system might be shipped or transported to any place, and then be laid down by comparatively little labour; whilst the nature of the soil, and other opponent causes, would have no practical effect in respect to the injury of electrical results. The economy is also very great in all respects.

The first cost is thus not only very little, but the usual heavy costs for maintenance and repair do not follow. It has been calculated that twenty miles of sections, containing fifty or more wires, may be laid in a day by thirty labourers. Mr. Nicoll suggested that the English government could quickly lay wires in this way from Calais direct to India, and possibly sufficiently compensate those nations for granting concessions for passage through their territories, by allotting a proportionate and free use of some of the wires. Messrs. J. Bourne and Son showed specimens of Varley's double-cup insulators, which are used to an immense extent in England (they are already illustrated at a previous page). In France, white porcelain single-cup insulators are employed; but these are very far inferior articles, and probably about the worst used by any nation as to their insulating qualities.

Messrs. Siemens Brothers had a very fine display of most valuable inventions. Having just noticed other insulators, we will first examine theirs. Efficiency in working the telegraph line cannot be ensured without good insulators; and no house has had more experience of the requirements of this important portion of the necessary appliances than Messrs. Siemens, under every condition of climates the most opposite. Under all circumstances, they have found that insulators of porcelain, strengthened and protected by iron, answer the best. The Siemens insulators are of two kinds—the stretching insulator, or "strainer," which secures the wire at definite intervals, usually of about 500 yards; and the intermediate insulators, six or eight of which are commonly placed at equal distances apart, between every two of the "strainers." Both sorts are on exactly the same principle, the only difference between them relating to the nature of the attachment of the telegraph wire itself. The principle of their construction is this:—An inverted porcelain cup, notched round its cylindrical shaft, is cemented by sulphur inside an iron flanged cap, or bell, which is fastened to the telegraph posts by special wood screws. Inside this inner porcelain cup a wrought-iron stalk is cemented, also by sulphur; this stalk terminating in the strainers in notches, and in the intermediates in simple turned-over hooks. These latter merely hold up the wire, and allow it to pass to and fro as it expands or contracts with the hourly variations of temperature. But in the notches of the strainers a circular turn of the wire is taken, which permits its being pulled through at any time, and thus tightened with ease should any slackening or yielding have taken place; or, by the same means, a portion of the wire may be released when repairs are making. These insulators have been employed for upwards of seventeen years with invariable success; and are in use in Russia, Turkey, Egypt, partly in India, Australia, Africa, and America. The value of an insulator depends on its equality of condition at all times. In the present examples the cast-iron bell protects the porcelain cup from harm, as well as from rain and wet; the iron stalk is coated with vulcanite, and rust is thus prevented, and at the same time increases its insulation; and there is nothing in all of the materials which tends to deterioration of electrical qualities by exposure to the atmosphere—as glass, for example, is subject to by the chemical change of its surface; and ebonite, by its shrinkage, causing num-

berless fine fissures, which are penetrated by the humidity of the air. Ebonite insulators, also, from their contraction, frequently drop out of their sockets, or burst when supported on stalks. Siemens' insulator has fairly proved itself one of the strongest and most durable of the kind. The object in reviewing these vast international exhibitions is not always to be seeking after novelties; it is useful and necessary to show, now and then, side by side with novelties and improvements, the standard articles, which, being perfect for their purposes, are enduring in their application, without change, and which, from exhibition to exhibition, be there five, ten, or fifty years between, would still be equally well entitled to space and to critical notice.

At the Paris Electrical Exhibition of 1881, telegraphy, of course, was a leading subject. Since the International Exposition at Paris in 1878, the principal development of electricity has been in the direction of electric lighting and the application of that subtle power to the performance of mechanical work. Nevertheless, there has also been a decided progress in one line of telegraphy, namely, the art of transmitting messages by the voice. At the time that exhibition was being held, Professor Hughes was prosecuting his fertile researches on the microphone, and the result is that by the additional force and refinement which the microphone conferred on the action of the Bell telephone, we were enabled to hear the music of the Grand Opera in the gallery of the Palais de l'Industrie. The unaided telephone falsified the sound of the voice which passed through it, and gave but a feeble echo of it, owing to the weakness of the currents and the overtones proper to the vibrating diaphragm of the instrument itself. But now, thanks to the improvement in the construction of that apparatus, and the stronger currents furnished by the microphone transmitter, the notes of the opera singers appear to come in all their purity, and even the footfalls of the ballet-dancers can be distinctly heard in rhythm with the music of the orchestra.

If the telephone has been decidedly improved since 1878, and several new forms of transmitter and receiver invented, the ordinary telegraph has, however, not advanced much since that time. It seems as if the ingenuity of electricians had been diverted into the new channels of telephony and electric lighting, for in the 1881 Exhibition we found practically the same telegraph instruments which were on view in 1878. The department of the French Telegraphic Administration contained the same variety of Hughes's type-printers, adapted for multiple transmission by M. Baudot, or duplex sending by M. Oillhaud; the same multiplex Morse apparatus devised by M. Meyer; Dujardin's telegraph, which delivers the message in groups of dots on a strip of travelling paper; and the autographic telegraphs of Caselli, Lenoir, D'Arlincourt, and Meyer, together with the usual display of simple Morse printers for wayside stations, and dial apparatus for local branch lines. There was, however, one novelty which we did not observe in 1878, namely, the electro-chemical rapid telegraph of MM. Chauvassaigne and Lambrigot, which prints the telegram in Morse characters. The chemical telegraph, because it does not involve the movement of any marking mechanism, is peculiarly adapted for quick transmission, and hence it has been resuscitated of late both in America and France. It possesses capabilities for this class of work which have perhaps hardly been done justice to thus far.

The pavilion of the French Telegraphic Administration, however, contained a variety of new experimental apparatus; for example, the radiophonic apparatus of M. Mercadier. There were to be seen the glass tube photophone receivers with smoked interiors, which he employed instead of the selenium cell and telephone of Professor Bell's original apparatus, independently, it is presumed, and concurrently with Professor Bell. The electric signalling lamp of the same inventor was also shown, in which the revolution of a cam with nicked edge is caused to pull back for a moment at stated intervals the upper carbon from the lower, so as to widen the arc and practically extinguish the electric light. The upper or positive carbon is vertical, and the lower horizontal, so that they are at right angles to each other, and the lower is continuously fed in order to present a fresh surface to the point above it. Sir William Thompson first applied this occulting principle to gas-jets for the purpose of enabling lighthouses to signal their distinguishing letters by the Morse code, both by cutting off the supply of gas with a cam and the intervention of an eclipsing screen. This apparatus was exhibited in the exhibition under the charge of Messrs. Latimer Clark, Muirhead, and Co. But M. Mercadier has gone a step further in realising the same idea with the electric lamp. Of course the eclipsing instrument of Sir William Thompson is applicable to electric as well as oil lamps; but M. Mercadier endeavours to prevent the loss of electricity which would take place by simply covering up the light, by only generating the latter when it is wanted; and if storage batteries come to be employed for lighthouse work, as it is very probable, his proposed economy will be practicable. There were other exhibits which will be described in the two following chapters of this work.

TELEGRAPHY PRACTICALLY CONSIDERED.

In the preceding pages an extended account has been given of the general principles of the electric telegraph, both on land or by submarine cables. We have explained the various sources of electricity employed for telegraphic purposes; the method of laying, suspending, insulating, etc., the conducting wires. We next propose to deal with telegraphic practice.

First, in respect to the *uses* of the electric telegraph. Our islands, continental Europe, and the United States, have now become completely netted over with telegraphic wires; and, in a less degree, India, Australia, and other distant countries, have largely adopted this mode of communication.

As a general rule, telegraphic arrangements have arisen from private enterprise. In our islands it has been exclusively so. First in the list of such undertakings was the Electric Telegraph Company, of which we have already given a short history. But the greatest telegraphic enterprise that has yet occurred was in the attempt to connect Ireland and America by a submarine cable, in 1857-'58. This undertaking was one unparalleled in any form of telegraphy, but was enthusiastically originated and supported by a comparatively limited number of private individuals, who subscribed each upwards from £1,000, the price of each share being that amount. Amongst those who took a spirited interest in the matter, we may especially name Thackeray, who, by his eloquence at a public meeting in Scotland, was the means of inducing many to embark their spare capital in the concern.

Disastrous as was the first attempt, still British pluck at last achieved success ; and, by 1866-'67, the Old and New Worlds were connected by two tiny wires sunk hundreds of fathoms deep in the ocean, each nearly 2,000 miles long, and which have since richly rewarded the enterprising shareholders. Next in importance to ourselves was the gradual laying down of a land line to India by the Persian Gulf. In Northern Asia, again, the telegraphic line is being gradually pushed across the continent from St. Petersburg towards China ; whilst in America similar progress has been made to connect New York with Francisco, and other important stations on the Pacific.

With but trifling exception, all this has been effected by private enterprise, aided by the highest scientific attainments, and the most profound practical knowledge that has been gradually acquired by telegraphic engineers. As we have already shown, the difficulties that have had to be surmounted were enormous. First, in respect to the long land lines, country had to be traversed that previously had been scarcely explored, and but slightly described in our best geographical works. Risks of all kinds, from savages resident or roaming on the route, arose. Indeed, the history of the laying of the Persian Gulf telegraph, both in the water and on land, from its incidents, reads more like the romance of an Aladdin, Sinbad, or Crusoe, than the account of an expedition for scientific and commercial purposes.

But, as telegraphy extended, other difficulties than those of a geographical character occurred. It has already been frequently noticed, that wires suspended in the air are free from the inductive influence that occurs to lines imbedded beneath the earth, or submerged in the sea. Conversing with Faraday several years ago, he expressed the view that this induction would militate against the successful use of long submarine wires. We have already, in his words, shown how such wires become equivalent to a charged Leyden jar. When the Atlantic cable of 1858 was first laid and used, this resistance of induction became a great difficulty. Conversing with the then electrician of that scheme, and others, it could only be gathered that the view of the practical working of that telegraph was confined to driving a current through its length. Subsequent discoveries, however, proved that idea to be fallacious ; and the genius of Wheatstone, Thomson, and others, converted the apparently insuperable difficulty into an element of success, that has been already fully described when we treated on the Atlantic cables of 1865-'66, and subsequent years.

Such results, here but briefly noticed, show how much may be done by private enterprise and intelligence. But still it must be admitted that the telegraphic system of this country has not had that development of which it is capable. The electric telegraph, to be a "great success," must be accommodated to the wants of all ; at present its use is restricted to comparatively few.

It was proposed, therefore, to take the entire management of the British Telegraph into the hands of the government, under the control of the Postmaster-General, and so to assimilate the postal and telegraph systems in one. This was done in 1870.

The daily press is a remarkable instance of the value of the telegraph ; but on this we need not enlarge, as we have already given instances of its value in this respect ; and similar remarks apply to its use by government, the police, and many other adaptations of the system.

The scientific value of the electric telegraph has been enormous. In the preceding article on Electro-Magnetism we have described many of the astronomical and meteorological uses of the telegraph. By its aid we have been enabled to rectify longitudes; "send time" to all the leading cities, ports, etc., of our island ; register meteorological observations ; and, in fact, perform a variety of other matters, to detail which would become wearisome.

We have already noticed, at a previous page, but very briefly, that atmospheric electricity has to be provided against by the practical telegraphist. This arises partly from the danger that the telegraphic operator is exposed to, and in part from the injury that may arise to the instruments by the destructive or inductive effects of the force. As previously mentioned, many varieties of apparatus have been invented to prevent the injurious effects of this atmospheric influence. The following article, quoted from an eminent and exceedingly useful periodical (the *English Mechanic*), fairly places the whole question in a scientific and practical point of view. It must be borne in mind, however, that it is not simply the thunder-storm that is a source of danger to the telegraphist. Any change of weather may induce, or be accompanied by, excessive presence of free electricity. Thus in March, 1868, a heavy thunder-storm occurred at Cambridge, accompanied by a heavy fall of snow. A dense fog is frequently associated with the presence of a large amount of free electricity, sufficient to derange the needles of the Wheatstone single or double-needle instruments; and even to cause danger to those

engaged in transmitting telegraphic intelligence by electrical arrangements.

The importance of the protection of the land overhead suspended wires is at once apparent, but equally so is the protection of the submarine cable; for whilst the former may be easily repaired, the latter might become irreparably injured by an intense atmospheric electrical discharge.

"Atmospheric electricity collects on telegraph wires, and often produces injurious results to the wire instruments and supports. Powerful electrical currents are produced in the wires of the telegraph by every flash of lightning which takes place within many miles of the line, by the action of dynamic induction, which differs from ordinary electrical induction, in being the result of electrical motion on the natural electricity of the conductor. When a storm-cloud, and consequently one powerfully electrised, approaches the earth, it decomposes by induction the natural electricity of all the more or less conductive parts that are at the surface of the ground. Its action may be arrested there if the wind brings near it another cloud, endowed naturally or by induction with an electricity contrary to its own. The explosion then takes place between the two clouds, and the portion of terrestrial surface whose electricity has been decomposed reverts to its natural state. But it may happen, also, that the discharge takes place between the cloud and the ground; in this case it will be the objects that are nearest the cloud, among those whose natural electricity is susceptible of decomposition, which will serve to transmit this discharge, and which consequently will be struck by lightning. Whatever may be the place where the lightning falls, it tends in preference towards conducting bodies that are found there, and towards metals. Thus lightning, in falling upon a house, sometimes carries away all the gildings that are found there, without injuring any of the inmates. It may be conducted through the metal rods and wires of a house without leaving any other trace of its passage than the fusion of the wires, while the conducting rods, being larger, have suffered no alteration.

"It will be thus seen, that the clouds, which are above the telegraph lines, being electrised by positive electricity, and the earth to which the wires are connected being electrised by negative electricity, the wires serve as conductors, through which the two electricities are neutralised, and an equilibrium established. If the wires be large enough to convey to the earth all the electricity which accumulates upon them, and the different parts of the apparatus were also sufficiently large, there could arise from such discharges no serious consequences beyond the temporary interruption of the working of the line. But as the wires of the electro-magnets are very fine, and incapable of conveying a large quantity of electricity, they are always melted or burned off whenever a great discharge is permitted to reach them. When the line wire was connected with the inner wire of the electro-magnet of Morse's telegraph, and whenever there was a discharge of atmospheric electricity, the coils exploded, sometimes causing serious effects. The line wires now connect with the outer wires of the coils; and whenever a discharge occurs, it generally burns off the small copper wire before reaching the inner part of the coils, and they are thus rarely ever seriously injured. In consequence of many accidents which have happened through the influence of lightning, every means has been tried to prevent these injurious results. Professor Henry's method of preventing the effect of the induction, which is the most fruitful source of the disturbance, is to erect at intervals along the lines, and aside of the supporting poles, a metallic wire, connected with the earth at the lower end, and terminating above, at the distance of about half an inch from the wire of the telegraph. By this arrangement the insulation of the conductor is not interfered with, and the greater portion of the charge is drawn off. This precaution is of importance at places where the line crosses a river, and is supported on high poles. Though accidents to the telegraphists from direct charge may be prevented by this method, yet the effect on the apparatus cannot be entirely obviated; the residual current, which escapes the discharge along the perpendicular wires, must neutralise for a moment the current of the battery, and produce irregularity of action in the apparatus.

"Steinheil, in 1846, invented the following contrivance. The main wire was extended over the station building on which the telegraph was placed. On the roof of the building the wire is divided, and on each end is fastened a copper plate, six inches in diameter. The part of the wire which is fastened to the plate stands in its middle perpendicular to it. Between the two plates is placed a thin silk cloth, so that the plates do not touch when in contact. In this vertical situation the plates are fastened through insulated supporters on the roof of the building, and protected from rain by a wooden box. By this arrangement the galvanic stream is cut off, as it finds an obstacle in the insulating piece of silk between. It is not so with atmospheric electricity, which, with little effort, can break through the interval between the plates. To make a perfect connection with the telegraph apparatus, the two wires from it are fastened each to the lower corners of the copper plates on the roof. A galvanic current can therefore pass down through the wire to the telegraph in the interior of the building, and, through the other wire, pass over to the second plate, in order to continue on through the main wire. The atmospheric electricity will, however, break through the small obstacle between the plates rather than pass out of the way through a thin and long wire in the telegraph apparatus.

"Breguet, the celebrated French electrician, proposed, that when the main wire was about fifteen or eighteen feet distant from the telegraph station, he would employ a very fine wire connected with the telegraph apparatus of the station, so that, in case of an electric discharge, it might melt the wires, and therefore save the station. Professor Meissner's lightning conductor

has proved frequently very effectual for the protection of persons and apparatus, the main wire coming from the next station on poles, insulated by porcelain boxes until in the neighbourhood of the building. It is covered by gutta-percha, and passes through pipes under the ground, and through the foundation walls of the telegraph office. Here it is fastened to a copper plate, 8 inches long, 4 inches wide, $\frac{3}{8}$ inch in thickness, by a screw. From this same copper plate extends a small insulated wire to the telegraphic apparatus, and through the battery to a second copper plate, and from this, again, by a stronger insulated wire, to the earth. The two copper plates are screwed together, but insulated by pieces of ivory, or gutta-percha, one-eighth of a line in thickness; the copper plates are then screwed on a suitable board, insulated and fastened on the wall of the telegraph office. The two thin wires, which are covered with silk, and twisted together, are once more jointly wrapped till near to the telegraph apparatus, when they again separate, and lead to the fixed cramps of the apparatus.

Another lightning guard, of beautiful construction, for protecting submarine wires which are connected with overland wires, has been invented by Siemens and Halske. It is formed of a tube of brass, connected with the earth, to three sides of which are presented sharp points of metal protruding from an arch. Several other lightning guards have been invented, and employed with success; but for full details of these particulars we must refer our readers to the work of Mr. Robert Sabine, on the electric telegraph.

In all these arrangements made for the protection of telegraph operators the principle is identical. Electricity of high tension, such as that produced by the ordinary electrical machine, or its equivalent, the flash of lightning on the large scale, can traverse the air, which to the ordinary voltaic current is a non-conductor. And not only so, the speed of the so-called lightning flash is instantaneous, and so its danger, if properly provided for, is as speedily dissipated. A plan of obviating the danger is extremely simple in theory, and only requiring adequate mechanical details to put it into practice. In our country the danger is generally of small extent compared to that of tropical countries.

Earth Circuits.—This subject has already been in part explained at a previous page; but the following additional observations will be of practical value.

"The rapid communication between points more or less distant is the object to be attained in constructing the electric telegraph. A single signal repeated at intervals from one station, and which can be easily observed at another, suffices to compose an alphabet or vocabulary.

"The electric current can be transmitted upon an insulated conductor to a great distance with sufficient intensity to produce marked effects, thus fulfilling, marvellously, all the anticipations of ancient and modern times for the instantaneous communication of thought.

"A system of electric telegraphy consists of an insulated wire conductor uniting two stations; a galvanic battery to generate the electric fluid; an apparatus to transmit the current upon the line, called a key, or manipulator; and an instrument to observe the passage of the current, called a receiver. We have already seen that, in order to have an electric or galvanic current, it is necessary that both poles of the battery should be united by a conductor. This conductor should be a metallic one; and, in order to have both poles of the battery united, which should be employed to communicate between distant points, it is evident that there should be two wires, one connected with the positive pole, for example, which should extend to a distant point, and a return wire connecting with the negative pole. This establishes the circuit, and the two electricities are obliged to traverse the entire two lengths of the wire in order to be neutralised by each other.

"However, it was subsequently ascertained that the earth itself formed an excellent substitute for the return wire, and that it was only necessary to bury the two ends of the wire of the termini of the lines at a suitable depth in the earth to form an excellent circuit. This important discovery, as far as voltaic electricity is concerned, was made in the following manner:—M. Gauss, an eminent electrician, whose experiments are doubtless well known to many of our readers, conceived the idea that two rails of a railway might be employed as conductors of the current for the electric telegraph. Another great electrician, M. Steinheil, having made some experiments with a view to realising Gauss's idea upon a railroad in Germany, was unable to obtain an insulation of the rails sufficiently perfect for the current to reach from one station to another. The great conductibility with which on this occasion he remarked that the earth was endowed, caused him to presume it would be possible to employ it as a conductor, which would enable him to dispense with one of the conducting wires between the two stations. The trials that he made to test the accuracy of this conclusion were followed by perfect success; and he then introduced into electric telegraphy one of its greatest improvements, both in regard to the economy produced by the suppression of one of the conducting wires, and of the facility resulting from it for the establishment of great telegraph lines. The transmission of electricity by the earth had already been accomplished by a great number of philosophers, but M. Steinheil was the first who proved the fact for voltaic electricity, and with the view of its application to telegraphy. The conductor of the telegraph constructed at Munich, in 1837, consisted of a copper wire, terminated at its extremities by two plates of copper buried in the earth; the current traversed this distance with the greater facility in proportion as the surface of the buried plates was increased. Mr. Alexander Bain, of Edinburgh, in 1842, made a great number of experiments on the conductibility of the ground, chiefly with a view to employing the earth as a moist conductor interposed between the zinc

and copper plates of a pair. He satisfied himself that a tolerably strong and very constant current was thus obtained. Mr. Bain afterwards succeeded in employing this current in order to make electric clocks go. M. Gauss had before this observed the appearance of an electric current in a wire placed in communication with the ground by large metal surfaces fixed at its extremities. Professor Wheatstone made also, at very nearly the same period, a great number of experiments upon the same subject, by studying the propagation of the current through the water of the Thames. The philosopher who first contributed by his labours, as ingenious as they were persevering, to give electric telegraphy its present practical character, is, without doubt, Wheatstone. This illustrious philosopher was led to this result by the researches that he had made, in 1834, upon the velocity of electricity—researches in which he had employed insulated wires of several miles in length, and which had demonstrated to him the possibility of making voltaic and magneto-electric currents pass through circuits of this length. To return to the theory of the earth circuit, we must not omit to mention the numerous experiments made by Signor Matteucci, on the conductibility of the earth for the electric current. He made the current from a single Bunsen's battery circulate in a copper wire 9,281 feet long, and through a bed of earth of the same length; and he found the diminution which occurred in the intensity of the current to be such, that the resistance of the bed of earth must not only be regarded as nothing, but that, further, the resistance of the copper wire entering into the mixed circuit must be considered as less than that presented by the same wire when it enters alone into the circuit. Experiments were made to ascertain whether this extraordinary fact was due to the passing of a voltaic current between the buried plates; but on closing the circuit with the earth, and the wire without the pile, a deviation not exceeding one degree was obtained, and this shortly disappeared. It then occurred to Matteucci that an explanation might possibly be given by having recourse to a current derived from Ampère's terrestrial currents. The battery current in the first experiment passed along the wire from E. to W.; he now reversed the current, causing it to pass from W. to E.; the deviation of the galvanometer, however, remained the same, as was also the case when the current was caused to pass from N. to S., or from S. to N. These experiments were afterwards repeated on greater lengths at Milan, and their results confirmed Matteucci in the conclusion to which he had previously arrived—namely, that when a current is transmitted by a circuit composed in parts of a long copper wire, and of a long bed of earth, the diminution suffered by this current from the resistance of this mixed circuit is less than that which it would have suffered by the resistance of the copper wire alone. The earth, as all other conducting bodies, by its great volume makes up for its inferior conductibility.

"Two electric charges, liberated at the extremities of the pile, always find means of diffusing themselves into the earth, which, being a universal reservoir, succeeds in neutralising their charges with its natural fluid decomposed by the free fluid of the pile.

"The improbability of the earth acting as a mere conductor is shown by the following experiments made by M. Breguet, the celebrated French electrician, between Paris and Rouen. One of the poles of the Paris battery was soldered to a large metal plate, which was plunged into a well; the other pole communicated with the line wire to Rouen, and was there fastened to a similar metal plate, which was also plunged into a well. The circuit was thus half earth and half metal, or the circuit could be made metallic throughout. Similar arrangements were made at Rouen. Two good galvanometers, in every respect similar, and working together with great uniformity, were employed to measure the electric forces at the two stations. The mean of twenty-eight experiments showed that, when the current was half metal and half earth, the intensity was twice as great as when it was metallic throughout; that is, a circuit of forty miles earth and forty miles wire presented the same resistance as a circuit of forty miles wire; the earth, in fact, offering no resistance at all. The intensity at Paris of the current transmitted through a copper wire to Rouen, and from Rouen back to Paris through the earth, was 56° 8′; that of a current sent and returned through a copper wire 29° 1′, or nearly one-half. At Rouen the mean relative intensities were the same, being 35° 5′, and 17° 8′. Many electricians regard the earth as a reservoir or drain, in which the positive electricity on the one side, and the negative on the other, are absorbed and lost. We will suppose the case of a single cell of a voltaic battery, P and N being its two poles united by a metallic conductor. According to the theory of Ampère, the electricity set free at the positive pole meeting with a resistance in the conducting wire, decomposes the neutral electricity of the nearest molecule, attracting the negative and repelling the positive; the positive fluid of the first attracts the negative electricity of the second, and repels its positive; this again acts on the neutral electricity of the third, and so on, the decomposition proceeding step by step, the positive electricity of the last molecule, p, being neutralised by the negative electricity emanating from the N. pole of the battery. Immediately succeeding the first series of decompositions is a second series of recompositions, the last negative molecule, n, being separated from its associated positive molecules, and this becoming free, now combines with the positive immediately behind it, and so on, step by step. Suppose now the metallic current to be broken between two free molecules $+p'$ on the positive side, $-n'$ on the negative, and that a communication be made with the earth through conducting metallic plates. The positive molecule will be brought into contact with an enormous reservoir, into which it will flow without meeting with any resistance; it will not, therefore, exercise any decomposing action, being in fact simply absorbed. The preceding negative

molecule being again set free, will immediately combine with the contiguous positive molecule, and the same will happen at the negative end of the battery. A double series of decompositions and recompositions thus takes place, and this only in one-half of the circuit; the resistance is consequently reduced to one-half of the circuit; that is, the intensity of the current is doubled." It must be admitted there is some difficulty in this theory of the absorbing of the electricity by the earth, and that the question is still open to investigation; but whatever may be the true explanation of this remarkable function of the earth, its discovery has been a great boon to electro-telegraphy; and the fact that the earth absolutely offers no resistance whatever to the circulation of the electrical force, is taken due advantage of on telegraphic lines.

Galvanometers.—Many forms of this instrument have been invented, and called by the names of the inventors, or from some peculiarity of construction.

The object of all of them is to measure the amount of dynamic or current force passing along a conductor by the deflection of a magnetised needle, placed inside a coil of covered copper wire. The single-needle telegraph apparatus, described a p. 517, *ante*, is really a coarse form of such an instrument arranged vertically; and the arrangement of the coil and needle is illustrated at p. 517, *ante*.

It is evident, in such an instrument that the greater the quantity of electricity passing as a current, the greater will be the deflection of the needle; and hence it is that such a deflector can be made a means of measuring the force of a current. The instrument is made increasingly delicate by an increase of the number of convolutions of the covered copper wire over the needle. Another great improvement consists in rendering the needle *astatic*. This is effected by using two needles, one suspended over and at a short distance from the other, the north pole of one being over the south pole of the other. By such an arrangement the needles are removed from the action of terrestrial magnetism, and are thus alone influenced by the passing current. This form is generally called Nobili's galvanometer. It consists of an astatic needle, suspended in such a manner as to move right or left within the coil of covered wire when a current of voltaic electricity is passed through the coil. A graduated index of a semicircle enables the experimenter to ascertain the angular deflection of the needle.

Such an instrument, however, not only registers the amount of current force, but is also used for its detection. Hence in telegraphy it has a double advantage; for not only can the constancy and normal force of a current be discovered, but, in testing for leakage through bad insulation, the instrument at once gives a sign of a passing current, proper arrangements being observed for that purpose.

The *sine* galvanometer has but one needle, and its name depends on the law that the power of a current varies as the *sine* of the angle of deflection. By means of a graduated rim, like that of the previously described galvanometer, the angle formed by the divergence or deflection of the needle is read off; and by reference to a table of sines, the comparative force of the current, as indicated by the angle, is obtained.

In this instrument it is, of course, evident that the terrestrial magnetism is allowed to act on the needle, only one being used, and not an astatic arrangement, as in Nobili's galvanometer, which has already been described and illustrated at a previous page; consequently, it is not so delicate in its indications, and should, therefore, be only employed for the measurement of comparatively strong currents.

The *tangent* galvanometer consists of a magnetic needle, suspended so as to move freely in a horizontal direction. Over it is a large hoop of copper; in the centre of this, the needle will be exactly in the magnetic meridian. In this instrument the amount of force is measured by the *tangent* of the angle of deflection—hence its name—and not by the sine, as is done in the last-described galvanometer. A reference to a table of natural tangents for the angle of deflection, will give the comparative or absolute value of the current force.

Weber's, as also Sir William Thomson's, reflecting galvanometers are of much delicacy; the construction and use of the latter, in connection with the laying and working of the Atlantic telegraph, have been already explained at a previous page. A mirror, made so light as to weigh but a few grains, rests in a direction north and south. By its deflection through the passage of a current of electricity, although extremely weak, the latter is not only measured, but the instrument is also capable of becoming an indicator for telegraphic purposes. Several modifications of this instrument have been made by Becker, Varley, and others. Many other forms of galvanometers have been invented, that were improvements on those which have preceded them, and led to the invention of some that have been here described.

Sources of Electricity.—In the preceding pages reference has mostly been made to the voltaic battery as a source of electricity for telegraphic purposes. In general terms, we also pointed out the principles on which the production of the voltaic current depends. But in connection with the practical part of our subject we must enter into more precise details.

The simplest possible form of a voltaic cell is that described and illustrated at p. 495, *ante*. It consists of two metals and a liquid. The action of the cell, so far as producing a current of electricity is concerned, does not commence until the two metals come in contact, immediately, as by touching each other, or mediately, as when connected by a wire. On either of such contacts being effected, a current passes from the zinc through the liquid to the copper, and traverses the wire back again to the zinc.

In such an arrangement, the conducting wire, above spoken of, represents the wire suspended overhead; or buried in the ground; or again, the submarine cable of ocean telegraphy. The indicating apparatus of any kind that has been

described, is affected in various ways, according to the construction or mode of working the instrument, between the two plates of the cell or battery, the latter being merely a repetition of one cell, arranged in such a manner that the zinc of one pair shall be connected with the copper of the next throughout the whole series, leaving a zinc plate unattached at one end, and a copper at the other.

Such an arrangement, whether of a single cell or a series, constitutes an early form of the voltaic battery, still used in the form of the *sand battery*. In this arrangement the fluid is replaced by sand moistened with acid and water. The use of the sand is simply that of preventing the spilling of the acid solution, although, practically, it has the advantage of maintaining greater constancy of action. A sand battery, properly charged, will last for weeks, or even months, in action sufficiently powerful, at all events, for use with Cooke and Wheatstone's single and double-needle instruments, described and illustrated at p. 518, *ante*.

But this kind of battery would afford far too little power for working such indicating instruments as those of Morse, and many others. These require sufficient electrical power or quantity to give mechanical motion to parts of the apparatus by means of electro-magnetic induction, in the manner already described. For such objects the sand battery would be quite useless, for the quantity of electricity it would supply would not be sufficient for such purposes.

It is true that, by increasing the *size* of the plates, the quantity of the battery power might also be increased, for reasons already explained. But many inconveniences would arise that need not here be pointed out.

A voltaic arrangement, of great value to the telegraphist, is found in Daniell's constant battery; like as in the simple cell just described, the metals employed are copper and zinc. The solutions used, however, differ. In Daniell's cell two liquids are used, being separated by a diaphragm of unglazed porous ware. Next the zinc is a solution of salt, or a dilute one of sulphuric acid, the latter being added to water in the proportion of from one of acid to ten, twenty, or thirty of water. Next the copper is a saturated solution of sulphate of copper in water, to which about an eighth part of sulphuric acid has been added. The zinc, if an acid solution be used, is first amalgamated by rubbing it over with mercury and dilute sulphuric acid, by means of which, as already explained, local action is avoided; and if the amalgamation be properly effected, no more zinc is dissolved than is actually due to the working of the cell or battery. At the same time the copper solution becomes decomposed. The hydrogen that would pass off from the copper surface, is employed in decomposing the oxide of copper in the solution, and consequently metallic copper is precipitated on the copper or negative plate. As this action proceeds, of course the copper solution becomes weakened; hence it is necessary to keep up its strength by suspending a tray in the liquid, supplied with crystals of the sulphate, that dissolve and replace the loss of copper in the solution.

Such are the general principles of the construction of a Daniell's constant cell, many modifications of which, however, have been made. One, suggested by Pouillet, the celebrated French *savant*, may be described, as it has been much used in France for telegraphic purposes. It consists of a hollow cylinder of copper, with a flat bottom, and a conical top. The cylinder (see Lardner on the telegraph) is ballasted with sand. Above the cone, formed by the top, the sides of the copper cylinder are extended so as to form a flange. Between this flange and the base of the cone, and near the base, is a ring of holes. The copper vessel is placed in a bladder which fits it loosely like a glove, and this is tied round the neck, under the flange. A saturated solution of sulphate of copper is poured into a cup above the cone, and, flowing through the ring of holes, fills the space between the bladder and the copper vessel. It is maintained in its state of saturation by crystals of the sulphate that are deposited in the cup.

The copper vessel is then immersed in a vessel of glazed porcelain, containing a solution of sulphate of zinc or common salt. A hollow cylinder of zinc, split down the side so as to be capable of being enlarged or contracted at pleasure, is immersed in the solution that surrounds the bladder.

About forty years ago we fitted up an arrangement somewhat similar, but preceding the above. Outside was an ordinary gallipot of two quarts measurement. Within this was a cylinder of zinc, charged with a solution of sal-ammoniac. Next, an ordinary porous garden-pot, with the lower hole stopped up by plaster of Paris. This was filled with a solution of sulphate of copper, and in it was immersed a cylinder of copper foil or sheet. Such an arrangement we found to be much more constant in action than the ordinary form of a Daniell's cell. Daniell made a special point, in his arrangement, of having an *external* cylinder of copper, with an internal rod or bar of zinc, from which he conceived that lines of force would radiate to the copper surface. In fact, in his earlier investigations, he placed as much stress on the value of the mechanical form of his battery as on its chemical principles—an error that subsequent investigations pointed out and corrected.

Moleyn's battery, described in Mr. Noad's early edition of *Lectures on Electricity, &c.* (1839), scarcely differs from that suggested by Pouillet; and, in fact, we have no hesitation in saying, that the claim of originality ascribed to that philosopher, becomes invalidated by the description and illustration given in Mr. Noad's work. It was to this that we were indebted for the first idea of constructing the arrangement just described as of our invention. This form of battery never came into any use for telegraphy.

An esteemed friend, the late Dr. Bachhoffner, suggested a modification of Daniell's battery, as follows, about the same period, and one that we have found of great use if moderate power, but constant action, be required. It is extremely simple in construction, and has, moreover, the advantage of cheapness. Of course, in this and the two precedingly-described apparatus, the bladder should now be substituted by porous earthenware.

"A piece of thin sheet copper is coiled up into the form of a cylinder, and retained in that position by a fine copper wire. The size I usually employ is that of four inches by two and a-half; it is then to be placed in a small bladder, which is secured round the copper by pack-thread, the top being left open, and the membrane forming the bottom of the cylinder; a piece of zinc is rolled up in a similar manner, a copper wire having been previously soldered to each zinc and copper plate, to form the connection. The battery may be placed in a jelly-pot. To excite it, pour into the copper cylinder a saturated solution of sulphate of copper; outside of the copper, and in contact with the zinc, must be placed another solution—it matters little of what nature; one of common salt I find to be as good as any that I have tried; and it has the advantage of being cheap, and always at hand. If the battery is required to be kept in action for two or three days, a few crystals of sulphate of copper must be added to the solution in contact with the copper."

We may notice that Dr. Leeson first proposed the use of bichromate of potass as an excitant liquid for a copper-zinc battery, but it came into little use. The chromic acid, being highly oxygenated, was employed to combine with the nascent hydrogen evolved from the copper plate; and hence, theoretically and practically, a certain form of constant battery was afforded, analogous in its action to Daniell's, Grove's, Callan's, Bunsen's, and others, in all of which the immediate absorption of hydrogen is the object. A modification of the bichromate battery is described as follows. A description of this kind of battery is taken from the *Proceedings of the Royal Society of Edinburgh*, 1849. Its use was proposed by Dr. Wright, of Edinburgh.

"The chromic acid battery was arranged by twisting round one end of a cylinder of coke a copper conducting wire; soaking the part in boiling beeswax, and afterwards covering it with varnish, to protect the wire from the acid. This coke was then surrounded by a cylinder of amalgamated zinc, and firmly fixed in its place by wedges of varnished cork. To form the exciting liquid, a measure of strong sulphuric acid was added to an equal measure of a hot saturated solution of bichromate of potash; the mixture was then diluted with four measures of water, and set aside to cool. The coke and zinc cylinders, placed in the solution, possessed a high degree of electro-motive force; a single pair being capable of decomposing water, with platinum electrodes. The author stated that the arrangement was not constant, its action gradually declining after immersion. . . . . In an experiment made by him with Professor George Wilson, a series of four pairs, roughly put together in half-pint tumblers, decomposed acidulated water at the rate of two cubic inches of mixed gases per minute with a cold, and four with a hot, charge of the above solution. One of the advantages of the battery was that a series of cylinders, however extensive, might, as in Wollaston's arrangement, be immersed at once, and the energetic effects of first immersion repeated at pleasure. Platinum, or box-wood charcoal, might be used in place of coke. A small series of thirteen pairs (box-wood, charcoal, and amalgamated zinc), each exposing a surface of a quarter of an inch square, afforded a shock equal to a Cruikshank's battery of fifty four-inch plates; a perceptible shock being felt even from four pairs.

At the present time a modification of the bichromate battery is employed for telegraph and other purposes. It consists of a plate of zinc as the positive element, and one of gas-carbon as the negative. The two are enclosed in a glass vessel and charged with a solution of bichromate of potass, binding screws being attached as usual. The arrangement is neat, cleanly, and effective.

Many years ago, Mr. Bain, so well known for his numerous contributions to electrical apparatus, but especially in regard to electric clock and telegraphic apparatus, suggested an arrangement, by means of which regularity of the battery action could be maintained. This apparatus has been designated a voltaic *governor*, from its power of controlling the electric force, as the governor of a steam-engine controls the supply of steam to the piston. In all forms of the constant battery, it is well known that the energy of the action declines in proportion as it is continued; and that though, for many practical purposes, the action may be assumed *constant*, and employed as such, yet it is in truth a diminishing action, which requires continual revival for continued operations. In this, as in all previous modes of adjusting the action to the work to be done, the sources of adjustment are entirely chemical. The mode adopted by Mr. Bain is different; and in this the novelty of his contrivance consists—that he employed mechanical power in conjunction with chemical affinities, causing the two forces to counterbalance each other, and produce an aggregate equilibrium of constant action of given power.

In America, and on the continet, where various forms of the Morse instrument are so largely employed, nitric acid batteries of different kinds are adopted. Of these there are three varieties—those of Grove, Callan, and Bunsen. In all of them amalgamated zinc is used as the positive metal; but the negative plate varies: in Grove's battery it is one of platina; in Callan's, one of cast-iron; and in Bunsen's, a plate, bar, or cylinder of the carbon or graphite deposited in gas retorts is used.

Next the platina or carbon plate of Grove and Bunsen, nitric acid, or that acid mixed with sulphuric acid, is placed; and this acid is separated from the dilute acid used with the zinc by

means of a porous diaphragm, as in Daniell's battery. As the action of the battery goes on, the hydrogen, that would otherwise be evolved from the platina or carbon plate, combines with the oxygen of the nitric acid, forming water. Gradually, of course, the nitric acid becomes weakened; and, eventually, when it is entirely decomposed, either Grove's or Bunsen's battery does not greatly exceed in power the simple or sand battery already described.

When Grove's battery was first brought out, it was proposed to employ a solution of potass, common salt, or sal-ammoniac as the exciting solution on the zinc side, so as to save the necessity of amalgamation. Here it should be noticed, that however carefully zinc may be amalgamated for use in such batteries as we are now describing, the nitric acid, that gradually finds its way through the porous cell, acts on the zinc to such an extent as, except for a short time, to render amalgamation comparatively useless. Indeed, in all batteries, if the sulphuric acid used to excite the zinc contain any nitric acid—a matter of frequent occurrence—the benefit of amalgamation is but slight, because it is wholly ineffective in respect to nitric acid.

Several years ago we were desirous of obviating the inconveniences here named, and found that a solution of chloride of zinc is an excellent excitant, being not much deficient in quantity production when compared with a strong solution of sulphuric acid, and at the same time it renders amalgamation unnecessary. Such a solution is easily made by dissolving old zinc in dilute hydrochloric acid, the common acid of the shops answering perfectly well. If a saturated solution be so made, it may be diluted with twice or thrice its bulk of cold water, when it will be found sufficiently strong for all ordinary purposes.

The great objection to the use of all arrangements in which porous earthenware cells are employed, arises from the constant fracture of them. Thus, if a porous cell be removed from the battery, and be left exposed to the air with no liquid in it, the zinc or copper salt will gradually crystallise in its pores, and break it to pieces.

It therefore follows, that, as soon as a porous cell is so removed, it should be instantly immersed in water, and left there until all salts are completely dissolved out. It is, indeed, an excellent plan to keep porous cells that have once been used constantly in water until again required. The risk of fracture from causes just specified then becomes *nil*.

The porous cells of Daniell's battery are apt to have metallic copper deposited in them, both in the mass and on the internal surface at the bottom of the pot. This, however, may be prevented by dipping the lower part of the pot, whilst new, into very hot melted wax, immersing it to a depth of half an inch. This will render that portion not only non-porous, but the grease or wax entirely prevents the possibility of either metallic or saline deposition. Similarly, if glazed earthenware be employed to hold the copper solution of a Daniell's cell, it should be first coated with either wax, pitch, rosin, or some such substance; otherwise, even with the best ware, the copper solution will gradually soak through, crystallise, and, consequently, destroy the vessel. Pitch, melted with half its weight of tallow, forms an excellent lining for all vessels intended to hold copper solutions. Of course, such would be entirely inadmissible for vessels intended for electro-plating, because the free potash, gradually formed from the cyanide of potassium, would soon act on such a mixture.

Referring, again, to the necessity and value of the amalgamation of zinc in all forms of voltaic batteries wherein dilute or strong acid solutions (as of sulphuric, nitric, or chromic acid) are used, the following remarks are worthy of notice:—

"Local action is the chemical action which takes place at the zinc plate, without sending electricity into the working circuit. Its principal cause is the impurity of the zinc, which sets up minor circuits between adjoining atoms. Pure zinc is nearly free from any action of the acid, but not wholly. Practically, we amalgamate the zinc, and find this a remedy; because the surface of the metal exposed to the acid is no longer a collection of galvanic elements, molecules of zinc, and negative metals intermingled, but one chiefly of mercury, and amalgams of mercury, on which sulphuric acid has but little action, and thus the minor batteries are destroyed. The surface becomes a smooth one; and as soon as a little action takes place, the hydrogen set free clings to the surface, and does two things: it polarises the plate; that is, it reverses to some extent its electrical states, reducing its affinity for acid, and it covers it with a film of gas which nearly keeps the acid from contact with it.

"This latter effect is visible at once, for a piece of amalgamated zinc covers itself with innumerable little balls of hydrogen. Now add a negative plate, unconnected, and that becomes oppositely polarised. They are now a battery with its circuit open; and, according to the natural tension of the battery, a slight current will establish itself, partly through the liquid and partly through the framework in a battery, maintaining a constant though small action at the zinc, which is partly deprived of its protecting coat of hydrogen, now set free at the negative plate, but almost wholly so when the circuit is completed.

"Let us now see the action as displayed in the bichromate battery [described at p. 545, *ante*]. Here, as in all cases, the hydrogen is set free at the negative or carbon plate, where it has a tendency to cling and arrest the action as before; but the chromic acid of the salt is reduced by nascent hydrogen, and thus the obstruction is not only removed, but the tension of electricity is increased, as the effect is similar to that of a second cell. Break the circuit, and the zinc is equally deprived of its protecting gas by the salt which seizes on it the instant it is produced, and by this additional affinity exalts the action of the acid, and, consequently, wholly destroys the second effect of amalgamation, and reduces the first. Therefore in this, or any other form in which nascent hydrogen is chemically absorbed, it is necessary to remove

the zinc from the agent used. In many forms this is done by the porous cell, as already described in connection with Daniell's, Grove's, and other double-fluid batteries, which involves the necessity of emptying the battery when not in use, and re-charging it when needed, otherwise the liquids mix by endosmose, and the zinc is soon destroyed. In the bichromate battery this is caused by the much readier mode of simply withdrawing the zinc, to prevent local action. It is probable that during action a slight loss arises from this cause."

The gas battery, first invented by Professor Grove, and now modified by the substitution of carbon plates instead of those of platina, has been already described. Smee's, and many other arrangements, have also been noticed. In fact, at the present day, the choice of chemical sources of electricity is very great, and almost every form of voltaic battery has been modified for special purposes or wants by telegraphists.

An interesting novelty in voltaic arrangements is that of Mr. De La Rue and Dr. Hugo Müller, in which the elements consist of silver and zinc, with chloride of silver as an electrolyte. This interesting form of a voltaic battery was first exhibited at a meeting of the Chemical Society of London, in March, 1868. It was the invention of the gentleman first named, and appeared remarkable at once for constancy and intensity. It is at least interesting as being a practical illustration of the truth of Faraday's laws of electrolytic decomposition; but its practical value has yet to be tested.

In 1880, Mr. Spottiswood and Mr. De La Rue constructed a battery of upwards of 20,000 cells of the chloride of silver battery, and obtained some most interesting results in a philosophical point of view.

Of recent years, Leclanché's cell has come into extensive use for such purposes as electric alarums, house telegraphs, and it has been employed extensively for telegraphic purposes on the large scale. The elements are zinc and gas carbon, and sal-ammoniac with oxide of manganese. This battery will last for months in action, gives a very constant current, and when the electro-motive force diminishes, the cell is easily recharged.

In making a choice of a voltaic battery or cell for telegraphic purposes, the electrician chiefly seeks for constancy of action. For use by business firms, the working of alarums, etc., the trouble of renewing solutions in the battery would forbid their use. Hence it is that Leclanché's cell has been so much adopted. It gives no trouble, and if properly managed, will keep in action for weeks or even months. But for telegraphing through great lengths, a more powerful arrangement is required. In this country Daniell's battery is used, and in the United States, and some parts of the continent, either Grove's or Bunsen's batteries are preferred. It is still a desideratum to telegraphists to find a battery fulfilling all necessary conditions. Perhaps now the dynamo-electric machine has been so far perfected it may at some future day be employed as a source of electricity for telegraphy.

Conductors and Insulating Substances.—For all practical purposes, copper and iron, in the form of wires, have been alone employed in telegraphy. In underground lines and submarine cables, copper alone is employed, because its superior conducting power permits of the use of a thinner wire than would be required if iron were used; for, as already pointed out, iron has a much inferior conducting power to copper. It must, however, be borne in mind that temperature has much to do with the question of conduction; for by an increase of temperature, all metals, as a rule, become depreciated in their conducting ability. For the following tables, by Dr. Mathiesen, we are indebted to Mr. Sabine's work. The conducting power of silver at 0° of Centigrade, or 32° freezing-point of Fahrenheit, was estimated at 100, and is assumed as the standard, because of its being the best conductor of all the metals in respect to electricity.

Table of the Relative Conducting Power of some Metals, at 0° Cent.

Silver, hard	100·00
Copper ,, ...	99·95
Gold ,, ...	77·96
Zinc	29·02
Cadmium	23·72
Tin	12·36
Lead	8·32
Antimony	4·62
Bismuth	1·25 nearly.

In the above table iron is not named. Its conducting power, compared with copper or silver, as 100, has been variously estimated at from 15 to 18: probably 17 would be near the mark.

It is hence evident, from these facts, that as the conducting power of any metallic wire is proportional to its sectional area, an iron wire, to have the same conducting power as a copper one, must be considerably thicker. Hence it is that such thick iron wires are employed for suspended wires. But another reason also arises from the necessity of sufficient strength to support the weight of the wire hanging between two contiguous posts.

The effect of an increase of temperature in diminishing the conducting power is manifest in the following table, which gives the power possessed by each metal, at 100° Cent., or 212° Fah.:—

Table of the Relative Conducting Power of some Metals, at 100° Cent.

Silver, hard	71·56
Copper ,, ...	70·27
Gold ,, ...	55·90
Zinc	20·67
Cadmium	16·77
Tin	8·67
Lead	5·86
Antimony	3·26
Bismuth	0·88 nearly.

It is evident, therefore, that temperature

greatly affects the conducting power of metallic wires. This does not seem a question of apparently great importance in land lines, because, if beneath the ground, the temperature is almost uniform for the year round ; and if suspended on poles, the large amount of battery power employed, always in excess of the demand, makes up readily for the deficiency. But in submarine wires, as coiled up in the hold of a ship, it has frequently happened that the cable heats to a surprising extent ; and, of course, if it were in the process of testing in regard to its insulation and other qualities, the circumstance of alteration of conducting power by temperature, would introduce an element of disturbance. It hence becomes a matter of great importance to the practical telegrapher, to ascertain the amount of increased resistance that is due to change of temperature ; and the subject has, consequently, been carefully investigated by eminent physicists. The result of these investigations leads to the belief that their conducting power diminishes in equal ratio for all, for an equal decrement of temperature within the limits of the freezing and boiling-points of water. In measuring the resistance of an electric wire (a subject which we shall subsequently have to investigate), this question becomes of great importance.

Independent of temperature, the quality of a metal greatly varies its conducting power. This has been already pointed out ; for we have stated that copper wire varies 50 per cent. in this respect. Hence the great care that is now taken in the manufacture of both copper, German silver, and iron, for conducting wires, and other parts of apparatus used for telegraphic purposes.

Great difference may be also noticed between the conducting power of hard, or unannealed, and soft, or annealed metals. Dr. Siemens states (Sabine) the difference to be as follows :—

	Hard.	Annealed.
Copper . . .	52·207	55·253
Silver . . .	56·252	64·380
Brass . . .	11·439	13·502

The standard being pure mercury, at a temperature of 0° Cent., or the freezing-point of water.

It has been asserted that the continual transmission of electrical currents through a wire alters its conducting power. This has always seemed to us to be the case ; and not only so, the continued passage of intense currents, even for a comparatively short period, we have noticed to always occasion an alteration in its molecular character, converting soft copper wire into a hard crystalline substance ; owing to which, even thick wires may at times be broken by the fingers. In 1855, we mentioned this to Faraday, and he confirmed the fact and opinion by his own experience.

Mr. Sabine very fairly puts the case as follows :—

"Professor Kirchoff says that the conducting power of any wire, at a given temperature, certainly undergoes change if electric currents are transmitted through it, and it is exposed to fluctuations of temperature. Schröder van der Kolk also says that the conducting power of a copper wire undergoes a change whenever weak currents are allowed to pass through it.

"If this were the case, of what use would be our resistance scales. Dr. Mathiesen has happily found this to be a fallacy. He allowed a current, from two Bunsen's cells, to pass through a series of wires of different metals for six days, at the end of which no change in their conducting power had taken place—a result which some experiments of our own [Mr. Sabine's], undertaken in the winter of 1862-'3, in Germany, with the view of determining the same question, completely corroborated. We connected a finely-adjusted annealed German silver [wire] resistance to a self-acting make-and-break apparatus, or 'Wippe,' which sent reversed currents from a battery of large Daniell's elements, at an immense speed, through it both night and day. In addition to this, the wire was kept in a recess in an iron stove in the laboratory, so that, without any interference on our part, its temperature was raised by day, at least, to the temperature of boiling water, and during the night descended to within a few degrees of the freezing-point. The battery was raised at intervals from one cell to twenty, during about six weeks, but the conducting power of the metal did not vary in the least. Suspecting this constancy might be due to the reversals, we repeated the experiment with a zinc current, made and interrupted with great rapidity, with the same results.

"The belief in the inconstancy of metals may have its origin in the discovery that all the old resistance scales and rheostats are no longer exact. This may have its origin in three causes :—1st. The greater perfection of our systems of measurement enable us to detect differences which may have existed before, but which we were unable to appreciate. 2nd. The process of annealing, which, when commencing with a hard-drawn wire, may extend over a very long time if the wire is only exposed to variations of the temperature of the atmosphere : and, 3rd. The oxidation of the surface when the air has access to it.

"There can be no question that much has still to be learned in this branch of science. Wires of German silver, and some other alloys, become, when exposed freely to the air for some years, so brittle as to be incapable of being wound up on reels without danger of occasional ruptures of continuity. That the brittleness is accompanied by a change in conducting power is probable. It remains, however, to find whether the exclusion of air, by means of some material (as paraffine), will prevent the brittleness in question, or if it is due to molecular changes of the alloy."

It is to the latter view, expressed by Mr. Sabine, that we would briefly draw attention. For at least twenty-five years past we have, more or less frequently, and sometimes for weeks together, had a battery of fifty cells (Grove's) in action. The conducting wires from

the battery were generally of copper, and had a thickness of at least a quarter of an inch. After some little use, they got so brittle as to readily break if bent once or twice. Every care was taken to get the best quality of metal, but to no purpose ; and hence, for the conductors of such powerful batteries we have long discarded wires, and used narrow strips of sheet copper soldered together.

Again, it is well known that if the terminals of an ordinary wire coil be twisted after currents of great power have been for some time sent through, they will break off short. In making some experiments on submarine explosions a few years ago, we employed copper wire coated with gutta-percha, supplied by the Gutta-Percha Company, of Wharf Road, London. After using such wires for a week, more or less, we experienced constant annoyance from the breaking of one, and sometimes both—not caused by any strain on either wire, for the arrangement we adopted rendered that absolutely impossible. The wires, in fact, were tied, side by side, to a rope, so that any mechanical injury from sudden or prolonged strain was impossible.

On examining the fractured wire by a microscope, the molecular change became evident. A crystalline appearance was plainly seen, and hence the wire had really become again into an unannealed state. Now this, Mr. Sabine, in the quotation already made, has shown must be accompanied by loss of conducting power.

The conditions under which these results occurred, so far as we were concerned, must have been practically quite disconnected with temperature. In our own opinion, the reason that Mr. Sabine did not find any change of conducting power in the wires that he experimented on in Germany was, that the constant heating of them to a temperature of 212° daily, *restored them by a daily re-annealing.* No such effect could have affected our results ; for the temperature of the wires could not have varied 20° all the year round.

Again, we found that by heating it red-hot, the wire had, as might be expected, all its softness restored. Even platina that has long been used in a Grove's battery, will get so brittle as to break on bending ; hence we have long made it a practice to heat such platina red-hot at frequent intervals, which not only has the advantage of keeping it free from brittleness, but also of freeing it from all dirt, and a thin film of air that settles on all polished surfaces.

So fully convinced were we of the importance of this matter, that, in 1856, we urged it strongly on the attention of Mr. Whitehouse, the then electrician of the Atlantic Cable Company. It is by no means impossible that some of the unaccounted-for breakages and failures of submarine cables may arise from this cause.

The conducting power of fluids is a question of importance in the construction of batteries, &c. It is remarkable what a difference subsists between their power in this respect and that of metals. Thus, whilst the same length and sectional area of silver would have a conducting power of 100,000,000, that of a saturated solution of sulphate of copper does not exceed $5\frac{1}{2}$; and one of common salt is equal to $31\frac{1}{2}$. Hence appears the desirability of approximating the plates of a voltaic battery as close as possible to diminish the section of the bad conducting liquid, and, consequently, the resistance to the passage of the current so opposed.

In respect to insulating substances, we have already said much in the preceding pages, and have described many of the best that can be, or have been, employed. We shall, however, perhaps have again to refer to the subject in connection with the laws of resistance, testing submarine cables, and other allied subjects.

The following practical observations, by Mr. Sabine, may be advantageously added to what has been already stated. He observes :—

"Efforts have repeatedly been made to insulate cables with india-rubber and other materials, with which it was professed that a conductor, covered with the same thickness, would suffer less loss of current than with gutta-percha ; but the fate of the attempt has proved in most cases the real value, and gutta-percha is still employed alone [or mostly, more correctly] in the insulation of large submarine lines.

"Specifically, india-rubber has a greater resistance than gutta-percha, by which the loss of current on a line insulated by the same section of perfect dielectric would certainly be less ; secondly, it has, at the same time, a small inductive capacity, by which the retardation of the signals would be less, and the speed of speaking through cable proportionally greater ; thirdly, it does not become plastic when moderately heated, and allow the conducting wires to fall eccentric, as is the case with gutta-percha."

Mr. Sabine then goes on to point out several objections to the use of india-rubber. First, there is great difficulty in putting on the wire evenly, and so as to ensure its full insulating powers, as in also making joints. It has certain chemical tendencies towards becoming a viscid mass when in contact with other bodies. It rapidly absorbs water, which of itself would form a powerful objection against its use for submarine cables. Dr. Siemens found, that after experimenting on various kinds of india-rubber, at the end of a period of 300 days, it averaged an absorptive power equal to three times that of gutta-percha placed under similar circumstances. Mr. Sabine observes :—

"Mr. Siemens attempted to overcome all these bad qualities of india-rubber, and to take advantage of all the good ones, by covering it up in a coat of gutta-percha. By this, it was anticipated that the absorption of water, and the danger of bad joints, would be prevented ; while a cable so insulated would possess the small inductive capacity and high insulation due to an india-rubber covering. The conductors were usually coated, first with Chatterton's compound, then one or two coats of india-rubber, and lastly with a tube of gutta-percha.

"Wires insulated in this way gave splendid results ; but it is to be feared that age does not spare them. It would seem, indeed, that

covered up in the tube of gutta-percha, india-rubber shows more disposition to decompose than otherwise, and in some instances bursts the outer tube in expanding.

"India-rubber has been applied to wire in a variety of other forms ; amongst which, that of Mr. Hooper is perhaps the most likely to obtain a place as a mode of insulating long lines.* Mr. Hooper's method consists in covering the copper conductor first with a coating of pure india-rubber, then with a coating of india-rubber worked up with oxide of zinc, and lastly with a coating of india-rubber worked up with flowers of sulphur. This triply-coated core is then baked for four hours, at a temperature of about 250° Fah., by which the india-rubber jacket becomes vulcanised, as sufficient sulphur penetrates the interior mass to make the whole combine into a compact, and possibly durable insulator. The joints are secured by baking them in a steam-jacket constructed for the purpose."

There is one peculiarity of gutta-percha to which Mr. Sabine draws attention. "Gutta-percha contains a volatile oil, which is expelled from it in time by exposure to the air, and more quickly by over-heating. In either case, as soon as the oil has left it, the material becomes brittle, and cracks. When submerged, however, or enclosed in an air-tight space, this volatile oil, which seems to be essential to its plasticity, cannot escape, and the gum lasts unimpaired for an indefinite length of time, which is equivalent to saying that cables will never fail through spontaneous deterioration of the gutta-percha after they are in water."

In reference to Hooper's plan of working up oxide of zinc with india-rubber, we have to remark, that some years ago we tried numerous experiments in incorporating metallic oxides, chlorides, arsenides, sulphides, &c., with pure india-rubber. In all cases we found, after a time, the substance of the rubber became entirely changed. It separated spontaneously into granular-like masses, that could only be, perhaps, called properly, "rotten." Of course elasticity, in respect to extension, was destroyed. We hope that Mr. Hooper's attempts have had a better fate.

Resistance Measurement, and Apparatus for the purpose.—In all conductors, whether solid or liquid, resistance, as we have already seen, is an element of the highest theoretical and practical importance. Even with the best possible conductor, such as silver, the current of electricity no sooner attempts to pass from its source than it suffers an impediment to its passage. The cause of this is by no means understood. We should naturally expect that the closer the particles of a body are together, the better should be its conducting power ; because if there really exist pores between the particles of a body, these we should presume are the chief hindrances to the passage of the voltaic current through the body. But that such is not the case is very evident ; for gold and platina, which have about double the specific gravity of silver and copper, are, as we have shown at p. 547, *ante*, much inferior in their conducting power. On the other hand, however, we find, as a rule, that expansion by heat lowers the conducting power of all bodies, as shown by the table at p. 547, where the conducting power of several metals, at a temperature of 100° Cent., or 212° Fah., is seen to be considerably less than that they possess at 0° Cent., or 32° Fah. It has also been stated that the average decrement of conducting power in reference to variations of temperature, is nearly equal for all metallic conductors.

But neither temperature nor specific gravity can be taken as accounting for the varying resisting power of equal lengths of conductors. Potassium, for example, which is lighter than water, has many million times the conducting power of that fluid. Fluidity, again, cannot be any very essential cause of the great difference that exists between liquids, such as saline solutions, and liquefied or fused metals, or even mercury—all of the latter having many million times the conducting power of any acid or saline solutions.

We may safely state, therefore, that the absolute cause of total or comparative resistance afforded by conductors is utterly unknown ; and, so far as our present data go, we have no basis on which to form even a rough idea, let alone an adequate theory of the cause.

But we are in a very different position if we inquire into the *ratio* that different bodies possess in respect to resistance ; and, still further, of that ratio as affected by length and other physical circumstances. Thus it has long been an established fact, that as we increase the length of a conductor, we, in the same ratio, increase the resistance that it affords to the passage of what we may call a nominal power of current. Thus if one foot of wire cause a unit of resistance, two feet will cause two units, and so on ; and consequently, in such perfect conductors as metals, if homogeneous throughout their structure, we can estimate their resistance with great nicety.

In the case of non-homogeneous conductors, such as metals in an impure state, of course many difficulties will arise, but these have, to a large extent, so far as telegraphy is concerned, been successfully overcome.

The art of measuring this resistance is one of great delicacy, and requires refined instruments. The *Rheostat* was one of the first instruments employed for this purpose. Respecting it, Mr. Sabine remarks :—"Wheatstone first overcame this [the difficulty in practice, from the length of wire required] by rolling the wire round a cylinder of dry boxwood, on which a worm was cut just deep enough to receive it comfortably; and to facilitate the variation of its length, the other end of the wire was coiled upon a cylinder of brass in such a way that the point where the wire touched the cylinder as a tangent to its circumference, should be the point of contact, and from this point the length of the wire on the non-conducting roller was measured. The cylinders of box-wood and brass

* See remarks on Hooper's core at p. 505, *ante*.

were fixed in bearings parallel to each other upon a wooden board. The worm on the wooden roller was cut from end to end, comprising about forty turns to the inch. The wire, whose thickness did not exceed the one-hundredth of an inch, was connected at one end to a metal cap, which covered the nearer end of the wooden roller, round which it followed the course of the worm until it left it to be wound upon the metal cylinder, to the further end of which the other end of the wire was connected. The metal cap was in permanent connection through a spring pressing on its periphery, with a terminal screw; while a similar spring contact kept the brass cylinder connected with another terminal screw, forming the ends of the system. The axis of the wooden roller was furnished with a pointer or index, which turned with it over a circular dial, and indicated the fractions of turns; whilst a straight bar between the roller and cylinder, graduated correspondingly with the worm of the former, showed the number of whole turns upon it. This instrument was for some time the chief one employed to measure resistances of various lengths of wire, and was intended for currents of intensity rather than quantity."

Another form of Wheatstone's rheostat was intended for the regulation of voltaic currents having, comparatively speaking, to overcome moderate resistances. It consisted of a wooden cylinder, upon which a thick (No. 16 gauge) copper conducting wire was wound, by a method resembling that of a screw-thread. A fixed metal bar carried a sliding spring, which constantly pressed against one of the coiled wires. By turning handles, the cylinder revolved, and according to the direction of turning, either lengthened or shortened the conducting wire.

Wheatstone also invented what was called a Differential Resistance Measurer. It is applicable to any form of galvanometer, and consists of a base-board with an arrangement of four wires and binding-screws combined in such a manner that two galvanometers may be placed in the circuit. A simple contrivance is also generally supplied, so that any disturbance of electrical equilibrium may be restored that may be caused by slight differences in the length of the conducting wires.

Jacobi's rheostat much resembles that of Wheatstone in its general principles and arrangement; and the same may be said of Poggendorf's rheostat.

Numerous other forms of the rheostat, or resistance measurer, have from time to time been invented; but the earlier kind, such as have been described, while very well for comparative experiments in the laboratory, on the resistance of moderately long circuits, were comparatively valueless for measuring the resistance of submarine cables, whether before or after submersion. And not only so, the early attempts at measuring resistance were of little value, because no definite standard had been settled. They much resembled well-made clocks, but having no definite standard of time to indicate.

As the extension of telegraphy was enlarged so it became necessary to find better means for measuring the amount of resistance afforded by wires, especially in respect to under-ground, land, and submarine cables. We have repeatedly stated, in the preceding pages, that these two kinds of electro-telegraphic conductors are subject to the retarding influence of induction, and, consequently, a new element is introduced in respect to the examination of their resisting powers. But perhaps the most important points, in respect to the measurement of resistance, reside in our power of testing the insulation of a submarine cable, both before and after laying it; and also of finding out the locality of any fault that may exist in respect to such insulation. One of the greatest scientific marvels of the day is, that by instruments, constructed on the known principle of resistance in respect to insulating and conducting bodies, we can detect, with a marvellous certainty, the place at which a defective point exists in an already laid cable, and, consequently, are enabled to repair it, and restore it to its pristine, or even improved electrical condition. It is impossible to exaggerate the importance of this fact; it was amply illustrated in 1867, when one of the Atlantic cables was found defective at a considerable distance from the American coast. Yet the electrical tests applied discovered the locality of the fault; the cable was hauled up from a depth of more than one hundred fathoms; was repaired, and afterwards performed its work satisfactorily. Of course the Atlantic cables are of much smaller diameter, as laying on the bed of the ocean, than such as are employed near shore—as, for example, in the various cables connecting our islands, and those with the continent; but the latter-named cables are constantly subject to all kinds of risks. Usually laying in not more than twenty or thirty fathoms of water, they have been frequently injured by being hauled up with the anchors of ships near the shore, and at some distance from it. It is not to be expected that persons committing, even unintentionally, damage to a cable, would report the fact. Indeed, not very long ago, the ignorance of a captain was exhibited by his attempting to cut one of the channel cables, that had been hauled up by the anchor of his vessel, with a hatchet—perhaps under the supposition that some unknown sea monster—even the veritable sea-serpent—had arrived to make his acquaintance. In any and all of such cases it is of the greatest value to be able to detect the locality of the fault, so that the cable may be repaired as speedily as possible.

It is a somewhat difficult thing to give a popular idea of the laws and methods of resistance measurement in land, under-ground, and submarine wires; but in principle it does not greatly differ from some of the most ordinary operations in life. It is well known, and established by law, that a gallon measure, imperial, shall contain $277\frac{1}{4}$ cubic inches in measurement or capacity, and hold as much distilled water as shall weigh ten pounds avoirdupois, or 10×7000 grains. The pint and quart measures are por-

tions of this, their capacity also being defined. Now, it is evident that such measures give us an adequate and full idea of different amounts in bulk and weight *constant* for the same liquid—as, for example, distilled water—but varying if two liquids are compared together; for, as we have just noticed, a gallon of distilled water, at a certain temperature (say 60° Fah.), will weigh exactly ten pounds. But if, in place of that liquid, sulphuric acid, or oil of vitriol, fill the gallon measure, then that quantity of the latter-named fluid would weigh $18\frac{1}{2}$ pounds; and if mercury were employed, the gallon would weigh upwards of 140 pounds.

Now a similar principle is involved in measuring resistances in electric wires. It is evident that if we find a certain length of telegraph wire afford, as shown by the galvanometer, a certain amount of deflection of the needle of that instrument when a definite power of voltaic battery is employed, it is easy to coil on a bobbin an amount of fine covered copper wire that shall give precisely the same deflection. In other words, the long telegraph wire, and the wire coiled on the bobbin, would each show precisely the same resistance in conducting the current. Hence the bobbin is just as much an electric measure of conducting power, or resistance of the telegraph wire, as is the pint, quart, or gallon measure in respect to liquids. Therefore a single coil may represent the resistance of one length of telegraph wire; two coils double that resistance; three coils treble that resistance; and so on. In general terms, we may say, therefore, that n coils may be made to represent n' lengths of telegraph wire, presuming every portion of the latter to be in precisely the same condition in regard to its conducting and insulating properties.

But the second part of our illustration has yet to be adapted to the explanation of these resistance coils. We have remarked, that if a gallon liquid measure be filled with liquids of varying specific gravity, then, although the bulk would be identical in all cases, the weight would vary. In a similar manner, if a resistance coil that exactly measured the resistance of a definite length of a perfectly conducting and insulated cable, be applied to measure the resistance of an exactly similar piece of cable with a defect of insulation or conduction, then the resistance coil that formerly was its equivalent measure, ceases to be so. The defect at once becomes apparent, on account of the cable and the resistance coil ceasing, as shown by the galvanometer employed to detect the fact, to afford equal resistance, or equal conducting power. To attempt, therefore, to send the whole charge of a current through a cable, would be like attempting to make a pint measure hold a quart. In other words, a certain portion of the charge would be carried away from the wire at the point of defect. If this defect be very large, then the whole of the charge will be lost; but in the case of only a partial loss, it is evident that the original resistance coil value of the cable will differ in a ratio to the length of wire on either side of the fault. To continue our former illustration, we may suppose a gallon measure to have a *small* hole half-way up its side. The moment any liquid poured into it rises *above* that little hole, it will begin to run out; but still, the capacity of the vessel being great, and the quantity poured in at a time large, the loss from the little hole will be, apparently, trifling. But, however small the loss is, it is a loss; and the amount lost in a given period becomes a measure of its influence. If the hole be very large, it would be impossible to keep the vessel full; consequently, the size of the hole becomes a measure of the ratio of the leakage. In precisely a similar manner can we first measure the leakage of a cable, and, knowing its length, detect, within a moderate amount of error, the place of fault.

We are, of course, now illustrating our subject simply in respect to cables that have been already laid. In the works, where the testing goes on continuously, it is by no means so difficult to arrive at a knowledge of the place of a fault. We have already, at p. 510, spoken of units of resistance in respect to the insulation of the Atlantic telegraph; and the preceding article on Conductors will still further illustrate the subject. Generally, such a term means the ratio of insulating power of an insulating substance—such, for example, as gutta-percha—to the conducting powers of a good conductor, as copper. Such *units* have had various terms, according to the principles on which they are established; as, for example, Ohmads and Farads (from Ohm and Faraday), as used in the extended table of submarine cables, given at p. 513, *ante;* Siemens' units; British Association units, &c., &c.

The following remarks in Mr. Sabine's excellent work (already frequently referred to), will give the reader some idea of the mode of testing a cable in respect to the measurement of the insulation resistance of its core. He observes—

"The first measurements of the electrical condition of submarine wires were made with a simple galvanometer [illustrated at p. 253, *ante*, Fig. 164], inserted between one end of the cable to be measured and one of the poles of a galvanic battery, the other pole of which was put to earth [see *ante*, p. 541, for definition of the phrase]. When the further end of the cable was put in connection with the earth, the current of the battery passed through both cable and galvanometer, deflecting the needle of the latter to a greater or less degree as the cable was shorter or longer, or the section of the conductor greater or smaller, than of some piece of cable taken as a standard. The test served to show, at the same time, that the conductor of the cable was entire, and gave a remote idea of its length. When the end of the cable was insulated, however, or dry and free in air, the current of the battery passed through the galvanometer as before; but, having to traverse the insulating medium surrounding the conductor, its intensity was materially lessened, depending on the degree of insulation of the cable. If no deflection was observed it was presumed that the cable was good; and if the current was

strong enough to deflect the needle, the magnitude of the deflection gave an idea of the magnitude of the faults through which the current found a complete circuit.

"The instruments used for this purpose were of a rough nature, badly insulated, and insensible to currents of small intensity. But, notwithstanding the obvious insufficiency of this method of testing, it did not entirely give place to a more scientific way until the date when the Malta-Alexandria cable was begun. The government tests applied to this core began, however, the work of civilisation ; the insulation resistances and copper resistances were expressed in one and the same unit, and were thus made directly comparable with each other.* The dependence of the resistance of the conductor upon the conducting power of the metal used, and upon its dimensions, and the dependence of the resistance of the insulating covering upon the specific resistance of the material, and its dimension, being known, these resistances were calculated, and the results compared with those found by actual experiment. Thus the electrical conditions of the cable were judged by the agreement of the results found with those expected.

"Dr. Werner Siemens was the pioneer who began this very serviceable work, and carried it through ; and after the first prejudice against innovation had been got over, electricians, one after another, fell into the same way of thinking.

"In manufacturing the core of a submarine cable, as much care is devoted to the selection of gutta-percha of high specific gravity as of copper of high conducting power. Both are only to be attained by freeing the commercial materials from impurities.

"The Gutta-Percha Company, of Wharf Road, London, have succeeded signally in the production of first-rate insulation. The way they secure this, is by selecting the best gum, and, after the process of cutting the imported blocks into small shavings, and masticating it at the temperature of boiling water, of straining the plastic material through sieves of fine wire gauze. By this operation almost all the natural impurities of the gum are removed, and the substance rendered homogeneous, and of low conducting power."

Mr. Sabine here gives some illustrations of great insulating power of certain cables ; which, however, will be found more fully described in the two tables given at pp. 513, 514, *ante*, of various submarine cables.

Instruments, termed *bridges*, or *balances*, are employed in insulation testing, such as Wheatstone's, Siemens', the British Association, and others. They are all constructed on the comparison of resistance between two or more sets of insulated wires, in the manner explained at p. 552, when we described the general principle of the construction and use of resistance measures. The number, variety, and intricate arrangements prevent us entering into their separate consideration ; but we may direct the attention of the student desirous of full information of the mathematical formulæ and practical results, to Mr. Sabine's *Electric Telegraph* (1867), p. 285, *et seq.*, where the instruments first named are fully described, and full investigations of their construction afforded.

* See tables of submarine cables, given at pp. 513, 514, *ante*, col. second and third.

Numerous precautions are required in testing cables, arising from inequality of the mechanical nature of the insulating material, and from other causes. It has been already noticed, that the insulation of the Atlantic cable has greatly increased since its submersion in the ocean, the same tests being applied in respect to the resistance of the insulating core as were applied during its manufacture. Mr. Sabine found, on testing a cable under a pressure of 600 pounds per square inch, that the insulation was improved to the extent of 14 per cent. ; the insulating material in this case being gutta-percha. India-rubber-covered wires gave opposite results.

Packing or Laying a Cable in a Vessel before Submersion.—It will be in the memory of all our readers, that whilst the attempt to lay a submarine cable across the Atlantic in 1865 was eventually unsuccessful, still, electrically speaking, no fault existed. The following account of the coiling of that cable, which may be taken as an illustration of the usual method, will therefore be both instructive and interesting in connection with our present subject of practical telegraphy. The *Great Eastern*, or the unfortunate *Leviathan*, as she was first named, was chartered for this purpose. That mighty vessel, "hugest of all that swim the ocean deep," had undergone an internal transformation, to fit her for her new duties as a cable-ship. The great object was to get as few coils of cable as possible—in fact, if possible, to have it all in one. Large, however, as the *Great Eastern* is, she could never hold the Atlantic cable in one coil ; for, apart from its weight, which was 5,000 tons, its bulk in one mass was simply gigantic—a coil 58 feet in diameter, and nearly 60 feet high, enough to fill Astley's theatre from the ground of the circus almost to the roof. It was disposed, therefore, in three circular tanks—one aft, one amidships, and one forward. Each of these tanks was of solid wrought-iron, water-tight, built on what is called the 30-foot deck ; and, with some minute differences, all were nearly alike in size—viz., 58 feet diameter, and 20 feet high. The forward tank was, from the shape of the ship, smaller in diameter than those amidships and aft ; but the heights of all were alike. In order to sustain the enormous additional weight which was placed on the decks when the whole of the cable was on board, the deck on which the tanks were erected was strengthened by a system of knees and deck-beams ; while the lateral pressure of the cable against the sides of the tanks was overcome by an arrangement of beams and supports, with the object of confining the dead weight of the cable to the centre of the ship, and preventing, or rather overcoming, the outward pressure of the enormous mass when the vessel rolled—as the

Great Eastern did roll—at sea. The three tanks held, respectively, 817, 803, and 630 miles of cable, giving a total length of 2,250 miles. The work of shipping the cable continued without intermission for three months. The total quantity of rope required to connect Valentia with Bull's Bay, Newfoundland, allowing for the 'slack' which should run out to prevent too great a strain on the cable, was about 2,300 nautical, or nearly 2,700 statute, miles. With this length a liberal margin was given of nearly 600 statute miles of rope for slack caused by currents, possible rough weather, and the avoidance of anything like unusual strain on the cable in the deepest water. Over one part of the route the depth is as great as from 2,000 to 2,500 fathoms, or nearly three statute miles—a depth, however, which is only considered of moment in case of rough weather in paying out, the mere strength of the cable being sufficient to bear its own weight in eleven miles of still water. In this respect—as, indeed, in all others—the cable had an enormous superiority over the old and ill-used rope which was first laid, and which, to the amazement of all those who knew its real condition, nevertheless remained in fair working order for a few days. In size, in strength, in better condition, better insulation, and better outer covering, the new rope was never less than three times as good as the old one ; while in many cases, and these the most important, its superiority was four or five times greater. Though a much larger cable, its weight in water per mile was less than half that of its unfortunate predecessor; its breaking strain was $7\frac{3}{4}$ tons, against $3\frac{1}{4}$ tons, the maximum strength of the old rope. The method of joining up the two-mile lengths in which it was constructed was also a great improvement upon the soldered joints in the wires of the first cable ; while the standards for insulation and 'conductivity' were as high as those devised for the Persian Gulf cable, and the tests are continuous in every portion of the manufacture."

The Persian Gulf cable we have already described as the best that had then been made (1868), taking every mechanical, electrical, and other condition into consideration. In our remarks on the resistance of the core of cables in respect to insulation, we have pointed out such conditions as relate to the success of submarine cables ; and it is needless to add, that in the Persian and the 1866 Atlantic cable, the best possible attention was paid to ensure the fulfilment of such conditions.

In connection with practical submarine telegraphy, the following extracts from a paper by Mr. George Elliot, describing the paying-out and picking-up machinery employed in laying the Atlantic cable of 1866, and the recovery of the 1865 cable, will be read with interest :—

"The objects aimed at in the Atlantic telegraph cable expedition of 1866, were—firstly, the laying of a new cable across the Atlantic ; and, secondly, the recovery and completion of the one commenced and lost in the unsuccessful attempt of the previous year [1865]. The cable to be laid was coiled in three circular wrought-iron tanks built on the main deck of the *Great Eastern ;* and was kept covered with water during the whole time of the laying, so as to prevent depreciation of the gutta-percha coating, and afford an effectual means of constantly testing its electrical condition. In paying out the cable, it was passed first over a series of six deep-grooved carrying wheels, called the jockey gear, and was pressed down into the grooves of the wheels by weighted jockey rollers, the wheels and rollers being all fitted with friction-brakes. The whole of the jockey rollers could at any moment be simultaneously lifted off the carrying wheels, so as to let the cable slip freely through the grooves, in the event of its ever being necessary to let the cable run in order to ease the tensile strain upon it. The jockey gear thus served the purpose of giving a preliminary frictional hold upon the cable during the paying out ; and the cable then passed to the main friction drum, round which it was coiled four times for obtaining a hold upon the cable. On the shaft of the drum were the two main brake-wheels, rendered self-adjusting in their action by the arrangement invented by the late Mr. Appold, and employed in each of the previous expeditions of 1865 and 1858. A weight was suspended from the friction strap, and the two extremities of the strap were attached to a lever at different distances from the fulcrum, so that whenever the friction strap was carried round in the slightest degree by increased friction of the brake, thus overlifting the weight, the obliquity of the lever slackened the strap, and allowed the weight to fall back to its proper position. The whole effect of the friction-brake could, at any instant, be taken off the main drum by a hand-wheel relieving the friction strap of the suspended weight by which it was tightened. Two of these main winding-drums were provided as a precaution, but only one of them was actually employed in laying the cable. A coupling arrangement was also provided for connecting the winding-drum through spur-gearing to a pair of trunk engines, so that the drum could be employed at any time for hauling in the portion of the cable already payed out, should any fault occur requiring such an operation ; and this constituted one of the most important improvements over the arrangements of 1865, when it had been necessary to hand the cable along the side of the ship from the paying-out machinery in the stern to the picking-up machinery in the bow, on any occasion of requiring to haul-in the cable ; and it was during this hazardous process that the cable was broken and lost in the former expedition. On leaving the winding-drum, and before passing over the stern into the sea, the cable was carried over a pair of wheels, midway between which was a weighted pulley bearing upon the top of the cable, and guided in a vertical framing ; this formed the dynamometer, indicating upon a scale the tensile strain on the cable at each moment by the degree of deflection of the cable under the loaded pulley. The total length of cable payed out was 1,851 miles ; and the time occupied in making the distance of 1,669 miles from shore to shore, was fourteen days.

"The new cable having been successfully laid, the next object was to recover the end of the cable lost in the previous year; and after splicing it to the additional length of cable brought out for the purpose, to complete the laying of the old cable. The picking-up machinery in the bow of the ship was made of much greater strength than the paying-out machinery, on account of the extraordinary weight and strength of the grapnel-rope employed for raising the lost cable, the breaking strength of the rope being as much as thirty tons. The exact line of the sunk cable having been marked by a couple of buoys, placed at a considerable distance apart by nautical observation, the ship was then made to pass slowly across the line of the cable, dragging the grapnel-rope; and the hooking the cable in a depth of two miles of water by the large five-pronged grapnel at the end of the rope, was ascertained with sufficient certainty from the increase of strain indicated by the dynamometer. After several unsuccessful attempts to recover the cable, in one of which it had been actually raised to the surface of the water, it was again hooked and raised 900 fathoms from the bottom, and then buoyed there; after which the *Great Eastern* hooked the cable again a few miles to the westward, and at the same time the *Medway* hooked it still further west. Both vessels then began hauling the cable up, and the *Medway* broke it at a depth of about 300 fathoms, so that the *Great Eastern* had then a loose end for raising to the surface, and the strain on the cable was much reduced immediately. The recovered cable having then been tested and spliced, the laying of the remaining 680 miles required to finish the original cable was proceeded with, and successfully accomplished."

The following remarks may be appended to show the difficulties attending the recovery of the 1865 cable, and the method adopted for that purpose:—

"The grappling and raising of the Atlantic cable of 1865 in 1,900 fathoms, or a little less than $2\frac{1}{6}$ miles of water (instead of three miles, as has been so widely understood), affords, perhaps, an even more striking proof of the resources of telegraph-engineering than the successful laying of the 1866 cable. There was, of course, no difficulty in finding the precise spot in mid-ocean where the end of the broken cable lay. But it was a question whether the grapnel would drag steadily along the bottom at such a depth, or whether it would catch and jump successively from one point to another. It was not certain even that, with such a weight of grapnel wire out, it could be told when the cable was hooked; and it was a matter of the greatest doubt whether, even if once hooked, the cable could be hauled to the surface, supposing, furthermore, that it were hooked within two or three miles of the broken end, so as to oppose but little friction in 'coming home' along the bottom, as a cable laid with but little slack must have done to be lifted at all through two miles of water.

"It is well understood that the course of the cable was first marked by buoys, and that the ship engaged in grappling—and there were four ships engaged in the task—first went, according to the wind, three or four miles to the north or south, and then drifted broadside on across the course of the cable, with her grapnel dragging. To pay out 2,300 fathoms of grapnel wire took from one hour and twenty minutes to three hours; and the strain on the dynamometer in 1,900 fathoms of water was then $7\frac{1}{2}$ tons, increasing to $8\frac{1}{2}$ or 9 tons, according to the motion of the ship. The cable itself weighed 14 cwt. per nautical mile in water, and had a breaking strength of $7\frac{3}{4}$ tons. When the steady strain on the grapnel line at the depth named exceeded 8 or 9 tons, it was concluded that the cable was hooked; and this was generally found to be the case. Hauling-in occupied five or six hours, the resistance occasionally reaching $10\frac{1}{2}$ tons. As the wire came in with the cable, the resistance due to the weight of the former lessened, and that of the cable itself increased. When at the surface, the strain on the dynamometer was from $7\frac{1}{2}$ to 8 tons, and the calculated strain on the cable was nearly up to its breaking weight. It was grappled ten times in all; and, besides being raised to considerable heights from the bottom, and then breaking or slipping off the grapnel, it was twice raised to the surface. The bottom of the ocean where the cable was raised was proved to be of ooze containing microscopic shells, and no accident can happen to the cable there unless it be purposely dragged for and broken—as it unquestionably now may be, by any evil-minded skipper having grappling gear of sufficient strength—or unless a wreck fell across it. It is now being confidently predicted by certain writers that both cables will soon be destroyed by icebergs. It is, of course, possible that they may; but the more the probabilities are examined, the less they appear. Even if thus destroyed, however, in the iceberg track, which is only 200 miles wide, the cable, being in shallow water there, can easily be raised and repaired."

Telegraphic Works.—The enormous expansion of the telegraphic system during recent years, has called into exercise a new branch of business that is rapidly increasing in extent and importance.

But, comparatively speaking, a few years ago, the uses of india-rubber and gutta-percha were confined to water-proofing, moulding, and a few other purposes. But the necessity of an insulating medium for the submarine cable, and under-ground land wires, has caused an immense demand for these materials; and not only so, has equally stimulated many branches of the metal trade. We have already pointed out that, in respect to wire employed for land lines suspended on poles, there are now firms engaged exclusively in its manufacture. We have also seen that numerous firms engage exclusively, either in the manufacture of submarine cables, the making of indicating and other telegraphic instruments, and various appliances essential to the maintenance or support of our telegraphic arrangements. Competition in this, as in all other business, has led to valuable results;

intelligence of inventors has been stimulated to the bringing out or perfecting of instruments by the great and increasing demand for them.

We have now several factories on the banks of the Thames for the manufacture of submarine cables. That of Mr. Siemens, established in 1863, and since enlarged, though not the largest, is by no means the least active as regards business. Siemens and Halske, of Berlin, are perhaps the largest and most widely-known manufacturers of telegraph instruments and contractors for land lines on the continent; and they have also in England a reputation for excellence of workmanship and design in all that relates to electrical engineering. For many years Dr. C. W. Siemens has conducted a kind of branch of the Berlin house in London, for the supply of instruments and stores; and the firm now styled Siemens Brothers, at present manufactures, at Charlton, submarine cables as heavy or as light as any yet made; their business in cable-making, since the establishment of their cable factory, has evidently far exceeded that of the large and rival works at Silvertown. Their improvements of the dynamo-electric machine have enormously increased their business. The firm were large exhibitors at the Paris Electrical Exhibition of 1881, especially in regard to electric light apparatus.

Telegraphic Communication in Trains.—Amongst the numerous and important applications that have been made of electro-telegraphy, few can exceed, in life and property value, the power of communicating between passengers, the guard, and the engine-driver in railway trains.

There can be scarcely one of our readers that has not, at some time, run a risk in respect to railway accidents, the prevention of which might have resulted if sufficient communication, above referred to, had been provided. Indeed, it is hardly possible to state any special instance of greater importance than another in this respect. An axle of a carriage may get red-hot through want of grease, and, consequently, break; a wheel may get off the line from a variety of causes; in fact, to enumerate all the cases that indicate the necessity of such a communication would be simply impossible.

The number of inventions that have been brought out to effect communication between the passengers and guard, or engine, or mutually for all, has been great; but the success has as yet been, comparatively speaking, partial. The reason of this will be self-evident on a little consideration.

On most of our main lines, a *through* train—that is, one which does not require change of carriage, as between London and Scotland, Holyhead, &c.—might readily be provided with an electric arrangement sufficient for the purpose, simply because the electric continuity between all parts of the train need not be disturbed.

But in *ordinary* trains, as they are commonly termed, such a facility does not exist. An excess of passengers at any station may necessitate the addition of fresh carriages; and these are generally added, according to the class, at different portions of the train. A "first-class," for instance, will be put at the middle or back of the train; whilst the less valuable lives of the third-class passengers will have their chance assigned to a position nearest to the engine, leaving them the opportunity of changing time for eternity in advance of their richer brethren.

It would be unreasonable to suppose that the persons ordinarily employed to thus change the arrangement of the carriages of such a train, would be able to re-make or re-arrange the electrical communication to be desired. But, independently of such considerations, many others arise that cannot here be stated, which yet will suggest themselves to the minds of our readers. The following gives an account of the early progress (1868) of attempts to establish electric communication in trains.

Colonel Yolland, R.E., states in his report to the Board of Trade, in respect of experiments recently made on systems of electrical communication between passengers and the servants of railway companies in charge of trains, that the London and North-Western Railway Company fitted up the express train that runs from London to Wolverhampton and back (125¾ miles) during each week-day, with Mr. Martin's electrical apparatus (which had previously been used on the royal train). The experiments commenced on the 8th of January. The train generally consisted of about nine vehicles, including vans at each end, but independent of the engine and tender. On several occasions extra carriages were introduced into the train, not regularly fitted with electrical communication, but provided for by spare couplings, usually carried in the guard's van, and conducting wire ropes, stretched along the carriages. These trains have been started by ringing the electrical bell in the front van by the action of the guard in the rear van from ten stations in each journey, the guard in the front van giving the signal to the driver. Although this communication has been made use of about 500 times, it has only failed upon three occasions, in consequence of the conducting wire having been unnecessarily twisted and broken by porters in the act of taking off the electrical coupling wires. The experiments of this train furnish satisfactory results. The London and South-Western Railway Company commenced making similar experiments with their Exeter express train on the 2nd of December, 1867, from London to Bideford (219¾ miles), the electrical apparatus employed being invented by Mr. W. H. Preece, which had been in use since May, 1865. Out of 714 starting signals given on forty-eight days by the rear guard, only seven had failed to be acknowledged; of these two were accounted for by the electric bell being placed on the tender instead of on the engine, and thus prevented from being heard by the engine blowing off steam; four failures occurred at Exeter station from the wire being disturbed. Various experiments were made from compartments in the different carriages of the trains; and Colonel Yolland stated that these experiments must

also be regarded as satisfactory. The Midland Company also fitted up an express train that runs from London to Leeds (201 miles) and back, on Mr. Preece's system, and commenced running on the 30th of December, 1867. The engine was not fitted with an electric bell, but only an indicator signal on the engine, which the driver might or might not see, and which he very frequently did not see. The working had been severely tested on this line, and failures arose from weakness of the battery, from mechanical defects in the apparatus, and other preventible causes. There had been failures reported on eleven days out of thirty-four. The South-Eastern Railway Company have, since July, 1866, run the 7.25 A.M. down, and the 3.45 P.M. up, mail train between London and Dover (88 miles), and other trains, from February, 1867, all fitted up with Mr. Walker's electrical system of communication between passengers, guards, and drivers. The 7.25 A.M. down mail started from Charing Cross, called at Cannon Street, and attached other vehicles, and dropped some at Ashford without stopping the train between Cannon Street and Dover. The communication was reported as having been perfect for forty-five days, but imperfect on three days. The corresponding 3.45 P.M. up mail train had only one failure, in which the communication with the engine only was imperfect, but perfect throughout the train, during the forty-nine days. In one train three failures occurred during fifty-eight days ; and in another, one failure in fifty-seven days. In the tidal train the apparatus acted well during fifty-six days. On a total of 327 trains, running between the 24th of November and the 29th of January, the electric apparatus appeared not to have acted properly on eight different occasions, besides six others where the train was not fitted ; while close upon 900 signals appear to have been given on the electric bell during the same period for the starting of trains ; and, on an average, twelve signals were given by the guards on each journey ; making up a total of 3,750 signals. These trains were all broken up and re-marshalled at the end of each journey. Colonel Yolland considered the working on the South-Eastern Railway to have been very successful, and understood that they propose to continue the same mode of working, adopting the electric signal for starting from stations on these particular trains. In conclusion, Colonel Yolland stated—

"As regards the possibility of establishing and maintaining electric communication throughout the entire length of a railway train, and from the compartments of the various carriages, I think it impossible, looking to what has been going on for a long time on the London and South-Western and South-Eastern Railways, to doubt that it can be done. It is also quite possible that some other mode may be feasible ; but I am sure that the electric, or any other system which may be adopted, must be very carefully looked after, and used at all times for the starting of the trains from the stations, and that it will not do to use it only occasionally, and expect that it will be found efficient when an urgent emergency arises requiring the servants of the company to be informed that something is wrong in the train. The more simple means of communication provided, the better it will be. Visual signals outside each compartment of a carriage, or on the engine, are useless, and only serve to increase the cost of the apparatus. Electric bells, to ring in the guards' vans and on the engine, are all that can be necessary. With respect to the question of danger arising to the train from the signal being made direct to the driver in the first instance, instead of only to a guard, I must observe that the working of traffic on any line of railway that will not admit of a train being stopped at a station under the protection of the station signals, must be badly conducted if this cannot be done with perfect safety ; and the instructions which have been issued by the railway companies who have made these experiments, direct that it will be proper, when an electric signal is given, to stop the train at the next station, unless the servants of the company can see that something is wrong that requires the train to be stopped at once. No mode of communication will, in my opinion, be efficient which does not provide that a signal shall be given to the driver in the event of a train breaking into two or more parts, which frequently happens ; and this can be effected with the electric apparatus ; and the cord which is now used on some lines of railway, for some of the trains, does this when that cord is properly secured. The prominent question for decision at the present time, appears to be—Shall railway companies be compelled, by legislative enactment, to provide the means of communication between passengers and the servants of the companies in charge of trains on certain of those trains ? And this decision should properly depend on the answers to the two following questions :—1. Is such communication necessary, in order to provide for the public safety ? 2. Is it practicable ? As regards the necessity for such means of communication, I believe there are few who will now contend that it is not necessary for the very long journeys which are taken by express trains without stopping ; and I have already expressed my opinion, founded on actual experience of what has been accomplished, that it is quite practicable. It should be first established for the trains running long distances without stopping, and a discretionary power be given to the Board of Trade to order its extension from time to time, or gradually, to trains running upwards of ten miles without stopping."

The views or opinions of practical men have greatly differed as to the best or most certain system that can be adopted. In March, 1868, Sir Charles Fox, the eminent engineer, stated his plans, in a letter to one of the London daily journals, respecting maintaining communication between engine-drivers, guards, and passengers, in the following terms—

"I venture to suggest that this might be most readily effected by insulating and connecting together, by wires, the present safety chains in such a manner that a galvanic circuit should

pass throughout the train whenever these chains were hooked together, as they always ought to be, before any train is allowed to leave a station.

"Upon the engine I would have an ordinary steam-whistle, fitted with a lever attached to the steam-cock, and so arranged that, while horizontal, the whistle should be silent; but when, at any time, it, by falling down, assumed the vertical position, then the whistle should commence sounding, and continue to do so until the lever was restored to the horizontal one.

"This lever I should have maintained in the horizontal position by the attraction of a piece of iron having magnetic power imparted to it by an ordinary helix, so that during the continuance of such current, the whistle would remain silent; but, upon the interruption of the current from any cause, the piece of iron would instantly lose its attractive power, when the lever, from its own weight, would fall into the vertical position, and, in doing so, would admit steam into the whistle, which would instantly begin to scream, and continue to do so until the lever was replaced in the horizontal position, in which it would be retained only by the current being re-established through the length of the train.

"The action of the apparatus would be as follows:—While the train was being formed, it would be necessary for the engine-driver temporarily to support the lever in the horizontal position, as otherwise the whistle would be sounding during the whole time of making up the train; but on receiving the signal that all was ready for starting, he would remove such support, when, if all was right, the piece of iron being magnetised by the galvanic current passing through the helix, all would be proved to be in order by the simple fact of the whistle being silent; while, on the contrary, if any one pair of the safety chains had not been properly hooked together, or the want of continuity in the circuit had occurred from any other cause, no current could be established, and, consequently, the lever would of its own accord fall down, and the whistle would instantly commence screaming, and thereby indicate that something was wrong, and the train not in proper order for its journey.

"From a train in which this system was in operation it would be impossible for a vehicle to become detached without instant notice being given to the engine-driver of something wrong having happened to his train, as the whistle would thereupon begin to sound, and would persevere in doing so until all was put right again.

"I need hardly point out that, should it be deemed desirable to afford the guard or passengers an opportunity of communicating with the engine-driver, any the most simple method of causing a cessation of the galvanic current by bringing about the disruption of the circuit would have the effect.

In the case of passengers, this might be done by something resembling an ordinary thumb-latch, which, being pushed into a hole, could not be got out again without the assistance of the guard, thereby removing any difficulty in ascertaining whence the signal proceeded.

"One of the most important features in this suggestion appears to me to consist in the fact, that, in the event of a vehicle breaking off from a train, or the occurrence of anything which would destroy the galvanic current—such, for instance, as the unhooking of two safety chains—a signal could not fail to be given, and that without the exercise of any human agency, and especially at a moment when, from the agitation produced by fear, mistakes would be most likely to happen.

"In this case, the state of things producing the danger would give the required signal; while, by any method with which I am at present acquainted, a signal has to be given after something has gone wrong by some one possessing the knowledge of an existing danger.

"In using this method, care must, of course, be taken to ensure metallic contact between the links of the safety chains, which must, therefore, not be covered with paint at the points of contact; to secure which, in all new vehicles, it would, perhaps, be well to coat these chains, not with paint, but with zinc, deposited by the electrotyping process.

"The insulation and connection of the safety chains would entail an outlay on each vehicle of only a few shillings—say at most twenty; and in making up a train, the porters would have to perform no one act but what is now required in the performance of their usual duties."

The preceding quotations and remarks illustrate the difficulties that were early encountered in endeavouring to secure intercommunication of guard, passengers, and engine-driver. Between 1868 and 1881, a vast number of inventions were brought out for similar objects, but still not with entire success. The existing plan is that of having in each carriage a small box enclosing a handle, by moving which electrical communication is, or should be, made with the guard of the train. To prevent frivolous use, a thin sheet of glass is placed in front of the box, and this glass has to be broken to give access to the handle. This having been once moved, cannot be replaced by the passenger, so that any attempt at unnecessarily stopping a train can be at once detected, and subsequently punished. But the adoption of this plan is but partial, and not always successful, as was instanced by the barbarous murder of Mr. Gold, on the Brighton line, in mid-day in the summer of 1881.

A new application of electricity, in connection with railways, and called the *Electric Railway Brake*, was shown in the Paris Exhibition of 1867. It was highly thought of by practical authorities.

The French Academy of Sciences, who have a permanent fund at their disposal for awarding prizes to inventors of useful contrivances for lessening the dangers and injuries to life arising from the pursuit of arts and manufactures, have distinguished this invention, after its having been experimented with for some months on some railways in France and Belgium, with a prize of 2,500 francs. The object of M.

Achard's invention is to bring railway trains to a standstill with the least possible loss of time when running at high speed, and to effect this result by an apparatus entirely under the command and control of the driver, without any assistance from brakesmen or other attendants. The trials of his apparatus have been made on the Chemin de Fer de l'Est, in France, where it was applied to the express trains running between Paris and Strasburg, and on the Belgian State Railway. The inventor laid before the Academy very favourable reports from the engineers of these lines; and M. Combes, the well-known professor of mechanics at the Ecole des Mines, at Paris, drew up a complete report upon the action of the electric brake, in the name of a scientific committee, upon whose proposition the above-named prize was awarded to the inventor." We may here remark that electric brakes are by no means a novel invention, many of them having been suggested, but failed.

"M. Achard supplies each brake-van or other vehicle in the train, to the wheels of which his brake is applied, with a galvanic battery of six Daniell cells, which he has improved for this purpose. He connects these batteries with each other, and with the engine foot-plate, by means of four wires passing through the whole length of the train, and properly isolated by a coating of india-rubber or gutta-percha. By means of these electric wires the inventor is enabled to create two distinct currents, either of which may be closed or broken by altering the position of a handle placed before the engine-driver. The action of these electric currents on each individual brake will be—if not readily, yet ultimately—understood by the study of the two figures showing the elevation of one brake as applied to the wheels of the vehicle. The locking of the wheels is effected by their own inertia in revolving while the train is in motion, which is made use of to supply the power required for closing the brake.

"Since this invention was first brought out, several other most ingenious additions and improvements have suggested themselves to the inventor; and these were also reported upon by the members of the French Academy of Sciences, and described by the inventor himself in various pamphlets. A lever, similar to that of the engine-driver, is to be placed in each compartment, so as to place it within the power of every passenger to stop the train instantaneously by locking all brakes, and ringing all bells for drivers and guards to attend; and another electric apparatus is to be connected with this, to show afterwards which passenger stopped the train, in order to enable the officials to make the parties responsible for stopping the train without sufficient cause. Whenever one carriage is uncoupled from the train, the wires, of course, break contact; and, there being no electric current, the brakes cannot be made to act except by a special arrangement of a somewhat more complicated character. It is, therefore, advisable to have common brakes on the tender and on one or two of the vehicles in the train, to provide for emergencies of this class. The express trains on the railways which experimented with M. Achard's brake, always had the usual tender brake, which, if used simultaneously with the electric brakes, produced an additional effect; but it was preferred by the attendants, in most cases, to use the electric brake without using the hand-work brakes; and this is considered by the inventor and his friends, and by the *savans* of the French Academy, ample proof of the practical utility of this invention, deserving the gratitude of the nation." This invention was soon forgotten.

Meteorological and Astronomical Uses of the Electric Telegraph.—At a previous page, we have mentioned that the electric telegraph has been of the highest use in regard to astronomy and meteorology. Consequently, on this fact it may also be remarked, that in every scientific requirement of our mercantile or naval marine services, these have greatly benefited by the extension of electro-telegraphic communication.

The late Admiral Fitzroy was amongst the first to suggest the use of the telegraph for the purpose of ascertaining, at fixed periods, the height of the barometer and thermometer, force of wind, and other meteorological phenomena, not only in our own islands, but throughout Europe. For a long time he had to contend with prejudice; and the opposition that led him to extraordinary mental exertion, doubtless caused his loss to the scientific world and society, effected by his own hand. Much is it to be regretted that he had not the courage to face all difficulties; for, at the present day, his system has not only been received after many consultations between the government and the Royal Society, but, as far as we can judge, has become an established fact.

It will be evident to the most casual observer, that an extended knowledge of facts in any subject is of the highest value. We will suppose the case of an observer, situated in a central position, receiving intelligence from every part within a radius of 1,000 miles. The individual becomes practically omnibiquitous. He can gather information from any desired point or place; and all that is required is a generalising intelligence to put the information he has gathered into a practical form.

The peculiar configuration of Europe, in respect to its inland and coast conditions, renders the study of its meteorology one of great difficulty. On the coasts of our islands and Norway the Gulf-stream impinges, causing a great increase of temperature beyond that due to simple latitude. Thus, although the north-eastern coast of the United States is in the same latitude with Ireland, or nearly so, the temperature, together with that of Newfoundland, is very different. Whilst we have a mild atmosphere, the American coast may be buried in snow and frost.

The inland portions of Europe, again, are subject to the temperature-depressing influence of flat lands, extending more or less from the White Sea to the Mediterranean. Consequently, if an east wind should set in, the east coast of our islands is correspondingly affected. Thus,

due to the Gulf-stream running from Mexico across the Atlantic to our islands, our western coasts may have a south, south-west, or westerly wind, loaded with moisture; whilst the east coast shall be visited by a keen east, north-east, or northerly wind, all but destitute of moisture.

It consequently follows, that all the ports of our islands, east and west, may be differently affected in a meteorological point of view; and it equally follows that a central line of our islands, taken *en masse*, must hold an intermediate position between the two extremes of warmth and moisture, and dry air with cold.

It is, therefore, of the utmost importance to obtain a continuous registry of the meteorological phenomena thus caused. By so doing we may, to a certain extent, foretel what kind of weather should occur within a limited period of the time that the observations are made—not, perhaps, in any or all cases with accuracy, but, at the same time, sufficiently near approximation can be arrived at to render the intelligence so conveyed of great value to the sailor.

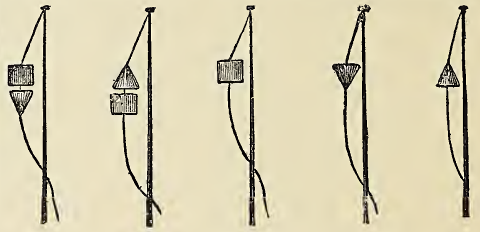
The obvious impossibility of giving accurate reports from each station, for reasons that will be self-evident, may, to a certain extent, invalidate the practical results that the electric telegraph might afford. Still any information that leads or tends to a saving of life and property cannot be over-estimated. It is a common practice, on the east coast of our islands, to send ships back to Newcastle and other northern ports in ballast; that is, having delivered their cargoes of coal in London, and having no return cargo, they receive into their hold sufficient Thames dredging to prevent any danger of their capsizing in ordinary weather. But at all times of the year the navigation of our eastern coasts is attended with danger. From the Nore, northwards, not much risk can occur until the vessel reaches Boston Deeps; but beyond there, even in summer-time, there is usually a heavy swell, independent of, although consequent on, storms in the North Sea. In autumn and winter the danger becomes greatly increased; and, annually, the loss of life and property, that by properly-arranged coast-signals might be preventible, becomes enormous. Fogs, again, are another source of constant danger, of which we have had frequent experience on the east and west coasts of our islands. Nothing in the experience of a life at sea can exceed, as a cause of anxiety, that of fog. The mariner is often all but unaware of his real position. Some years ago we had occasion to travel by sea from London to the Shetland Isles, and shall not readily forget the dangers of fog, and a following storm, during winter-time. But, in a well-appointed steam-vessel, much can be done to mitigate the dangers so caused. It is in coasting service of small vessels, especially in the fisheries of our islands, that the greatest danger is incurred; and hence the value of electro-telegraphic communication from a central station to distant ports to notify danger.

But much discretion is required in collating all the data supplied from distant stations; and an extended knowledge of meteorological science is necessary to generalise such facts.

If, therefore, science at times *seems* at fault, the defect must be laid simply to the imperfections of human power, rather than to any uncertainty in nature. The ordinary course of natural phenomena is governed by laws originated by the Creator. Man *may*, and *must*, err from want of perception; nature can never diverge from the laws impressed on its existence.

Supposing the necessary facts have been gained by telegraphic communication from various ports throughout Europe, the next step is to generalise and render them of avail to the mariner. This is followed by telegraphing to each port; and, according to Fitzroy's system, certain signals were hoisted, indicating any probable change of the weather. The following signals were first prepared by the late Admiral Fitzroy.

No. 1 denoted that a dangerous wind would probably at first arise from the southward. No. 2. Dangerous wind probably at first from the northward. No. 3. Dangerous winds may



No. 1. No. 2. No. 3. No. 4. No. 5.

Fig. 282.

be expected from nearly opposite quarters successively. No. 4. Gale probably from the south ward. No. 5. Gale probably from the northward.

In the early part of 1868, these signals, that had for some time been disused, were again, in a modified form, adopted by a newly-organised department of the Board of Trade; but not until great pressure had been made on the let-alone practice of governmental departments. A kind of semaphore was substituted for the preceding system, but the general principle was simply that of stating what kind of weather prevailed at different parts of the coasts of our islands at a definite time, so that vessels about to sail from or to any port might be advised in respect to the weather generally or specially prevalent. The following table for a specific date, illustrates the results of meteorological telegraphy for Europe generally.

It will be evident, from a perusal of the table, that the electric telegraph supplies every possible data from which conclusions can be drawn in respect to meteorological phenomena. We must refer our readers to the Report of the Board of Trade for further particulars in respect to such matters, as our object here is not to discuss meteorological phenomena, but only to show how the electric telegraph is applicable to their registration.

Telegraphic Reports of the Weather.

March 30. Eight A.M.	Bar.	Tem.	Wind.	Force 1 to 12.	Extreme F.	Extreme Direct.	Weather.	Rain.	Sea. 1 to 9.
Nairn.........	30·36f	50	W	3	1	WSW	c.o.	—	1
Aberdeen....	30·41f	43	SW	1	1	SSW	o.b.	—	1
Leith.........	30·45f	50	WNW	2	1	NNW	m.b.	—	—
Ardrossan ...	30·48f	48	WSW	2	3	SW	c.o.	—	1
Greencastle..	30·49s	50	WSW	1	2	WSW	c.o.	—	—
Valencia	30·55f	47	S	3	2	SSE	b	—	4
Cape Clear...	30·55s	44	E	1	2	SW	m.	—	1
Roche's Pnt.	30·56s	45	N	2	2	S	b.	—	1
Liverpool ...	30·56	44	Z	0	2	E	b.f.	—	1
Holyhead....	30·52f	46	SSW	1	0	Z	b.m.	—	—
Penzance	30·56f	43	Z	0	3	E	c.b.	—	2
Brest	30·47f	43	NE	4	5	NE	o.	—	4
L'Orient.....	30·43f	37	NE	3	3	ENE	b.	—	2
Rochefort....	30·32f	37	ENE	4	5	NE	c.b.	—	3
Corunna.....	30·30	53	NE	3	—	—	b.	—	—
Plymouth....	30·56f	39	Z	0	3	NE	b.m.	—	1
Weymouth ..	—	—	—	—	—	—	—	—	—
Portsmouth..	30·53f	42	E	2	2	WSW	c.	—	1
London.......	30·55f	37	Z	0	2	NE	c.b.f.	—	—
Yarmouth ...	30·54f	42	N	2	3	NNE	c.o.	—	2
Scarborough	30·51f	40	SW	2	2	SE	b.	—	2
Shields.......	30·52f	45	NW	2	2	SE	c.m.	—	2
Skudesnæs ..	30·45	39	ESE	2	2	S	c.	—	2
Cuxhaven....	—	—	—	—	—	—	—	—	—
Helder	30·51	40	NNE	3	—	—	—	—	2
Brussels......	30·48	47	NE	3	—	—	c.	—	—
Paris	30·45	39	NE	2	—	—	c.	—	—
Strasburg....	—	41	N	6	—	—	c.	—	—
Lyons	30·20	39	N	3	—	—	b.	—	—
Heart's Content (6 A.M. local time).	30·13s	21	NE	3	3	NE	s.	?	3
				Two P.M. Report.					
Nairn.........	30·39	58	WSW	1	—	—	c.	—	1
Greencastle..	30·49	54	WSW	1	—	—	o.	—	—
Valencia......	30·57	54	SW	3	—	—	b.	—	2
Penzance.....	30·51	52	ESE	3	—	—	c.	—	2
London	30·47	48	E	1	—	—	f.c.	—	—
Scarborough	30·47	50	SW	1	—	—	c.	—	2
Paris	—	—	—	—	—	—	—	—	—

"Barometer corrected and reduced to 32 deg. at sea-level. The letters—r, rising; f, falling; s, steady—indicate direction of motion of the mercury within the last 14 hours. Thermometer exposed in shade. Extreme force with its direction during last 24 hours. Z., calm. Weather: b., blue sky; c., clouds (detached); f., fog; h., hail; l., lightning; m., misty (hazy); o., overcast (dull); r., rain; s., snow; t., thunder. Rain-fall, snow or hail (melted), during last 24 hours. Sea disturbance.

"*Remarks.*—Barometrical pressures yesterday morning were very high, having increased since Saturday: all those recorded in these islands exceed 30·5 inches. This morning, though the readings are still high, some diminution has taken place. Pressures are lower in the extreme north and south than they are elsewhere: in England and Ireland they are very uniform. Temperature at southern stations has fallen since Saturday, but in Scotland the weather is somewhat warmer. The wind yesterday on our Channel coast was light from the eastward, and in the north and west variable. Calm is reported this morning in the south of England, but on the Irish coast the wind continues very light and variable. Mist has prevailed during the 24 hours on all our coasts, and continues in the Irish Channel and in the south of Ireland. Two P.M.—In the north and west of our islands a slight increase of pressure is shown since the morning, whilst on our south and east coasts there has been a diminution."

In our article on Electro-Magnetism, we gave the method of "sending time" to different stations in our islands, and also described several forms of electric clocks.

The importance of the electric telegraph, in respect to astronomical science, cannot be overrated For many years, the problem of solving the longitude of two or more places on the earth, compared with a standard place, as Greenwich, Paris, Farro, &c., remained unsolved. As one of our most eminent mathematicians observes, in his work on Nautical Astronomy (Professor Young)—"To determine

the longitude is justly regarded as the greatest achievement in nautical astronomy; it is often considered also as the most important." The earliest attempts were to construct a chronometer, that, being of great accuracy in respect to keeping time, should, by the observation of any particular planet or star at any place, give the time, and, consequently, the longitude of any place distant from Greenwich, which is our national standard in respect to the calculation of longitude.

For the information of the non-scientific reader, it may be observed, that astronomically, time and angular distance are convertible terms. Thus, the earth may be supposed to be divided into 360°, as regards its circular surface. It revolves once *nearly* in twenty-four hours, and, consequently, every 15° of space is equivalent to one hour of time, and therefore a degree of space passed through corresponds to four minutes of time; for as each hour has sixty minutes, and the twenty-four have 24×60 minutes $= 1{,}440$ minutes, that amount, divided by 360, equals four minutes, or—

$$\frac{1{,}440 \text{ minutes}}{360 \text{ degrees}} = 4'$$

It consequently happens that a star will be above the horizon at a place east from Greenwich *earlier*, and at a place west of Greenwich *later*, than at the observatory of the latter place. Now it is evident that the difference of time of the rising, culmination, or setting of the sun, planet, or stars, will, by conversion of time into space, give the longitude of the place in reference to 0°, or that of Greenwich.

Formerly the method of determining longitudes was confined to the observation of the position of heavenly bodies at a certain time. It is evident, that whilst at Greenwich the moon, sun, or any other body may have a certain altitude, at a place east of Greenwich that body will have a greater, and at one west of Greenwich a less, altitude. If a chronometer could be constructed with *absolute* accuracy, and at each station one was placed, then by means of simultaneous observation of a star, moon, &c., the relative longitudes of any two or more places could be accurately determined.

But electricity, travelling with a speed presumed to be equal to that of light—but, in any case, infinitely beyond the requirements of the astronomer—gives us a means of instantaneous communication between any two places. For example, we may suppose that it is desired to ascertain the longitude of Dublin in reference to Greenwich. At an agreed time observations at both places are made in respect to the position in the heavens of a certain star. At the moment of such observation the "time" at Greenwich can be instantaneously communicated to the observer at Dublin, and, consequently, the two observers are practically together; but the difference of the altitude of the star at each place, converted into time, and thereupon into angular space, gives the relative longitude of each position of observation. There are many other astronomical uses of the telegraph.

Indian Telegraphy.—Our possessions in India (Hindostan, etc.) embrace a peninsula reaching from the Himalayan mountains to Cape Comorin, bordering on Ceylon. Washed on the west by the Arabian Sea, by the Bay of Bengal on the east, and the Indian Ocean on the south, with an area of about 1,500,000 square miles, and a population of about 200,000,000, it is needless to add that any system of telegraphic communication must necessarily have an opportunity of development that cannot eventually be equalled in any part of the civilised world.

The diversities of climate, production, etc., of British India all add to the chances of telegraphic and railway communication being not only of the utmost value, but of being, at the same time, improved to meet all the wants of the country. Its productions include nearly every variety found on the face of the globe: rice, maize, millet, pulse, and various bread-stuffs are in enormous local use as food. Cotton, sugar, jute, hemp, indigo, opium, cocoa-nut oil, pepper, tobacco, ginger, spices, dye-stuffs, drugs for medicinal use, cocoa, coffee, tea, great varieties of forest and ornamental (woods) timber, form the staple trade of the land. Besides which, are "precious" productions, such as diamonds and other gems; gold, coal, and many metals; salt, borax, nitre; the skins of most of the carnivora, with many other products that our limited space prevents us from enumerating.

At one time this rich country was in the hands of a monopoly, familiarly known as the *East India Company.* But although, at the present day, its resources are open to the enterprise of any man or firm, they are as yet comparatively undeveloped, and must, from the extent of the country, remain so for many years, if not ages, to come.

The imports of India from our islands, in respect to produce, manufactured goods, etc., exceed in value £50,000,000 sterling annually; whilst we receive from our Indian possessions a far greater amount, independent of the imports or exports of bullion either way, which are about equal in amount to double the value of the goods taken from our islands at certain periods. Of course the effects of the American civil war have told largely in this respect during 1862 and following years.

Calcutta, Madras, and Bombay have, on an average, a population of 900,000 each. But, besides these, which may be termed the capitals of India in respect to European connection, are Delhi, Lahore, Cawnpore, Moultan, Allahabad, Agra, Hyderabad, Kurrachee, Surat, Patna, Aurungabad, Hydrabad, Poonah, Goa, Seringapatam, and many others of almost equal importance, all of which are connected, to a greater or less degree, with the mother country in questions of commercial reciprocity. It must be also borne in mind that India may, so far as our eastern commerce is concerned, be considered as its general focus, more especially as Hindostan is the chief station at which all, or nearly all, the mercantile marine call *en route* to China, Japan, Burmah, the Pacific Islands, and adjacent localities.

It is not a matter of surprise, therefore, that Indian telegraphy has been considered as of scarcely less importance than any other, save that of America, in connection with our islands. But the progress, both in and out of India, as regards England, has hitherto been very slow in result. The following gives its early history.

"It is generally, though erroneously, believed that under the designation of the *Indo-European Telegraph*, is comprised a complete telegraphic system under an English administration, responsible for all the shortcomings and delays in the telegraphic communication between England and Calcutta. In reality, the only portion of the telegraphic system between India and England which, bearing this official title, is under English management, consists of the Persian Gulf cable between Kurrachee and Fao, a Turkish village at the head of the Persian Gulf. From Fao a Turkish suspended land line extends to Constantinople, thus completing the chain of communication between India and the various land lines of European Turkey, which again carry on the communication to the Austrian and Italian lines. This long connecting line was erected by the Turkish government. It was commenced in or about 1857, the work being at first carried on under the direction of Colonel Biddulph, R.E., and a staff of English sappers, lent by the English authorities, but paid by the Turkish government. Some difficulties between Colonel Biddulph and the Turkish officials occurring when the line was about half finished, that officer resigned, and the Turkish government alone completed the line, as far as Bagdad, in about 1861; and, for several years, this far-famed town formed the extreme eastern terminus of the telegraphic system extending from England in the direction of India.

"In 1862 the Indian system of telegraphs had been extended from Kurrachee, westwards 270 miles, to Gwadur by a land line specially erected, under the name of the Mekran telegraph, by Mr. J. Walton, of the Indian telegraph department; and, in the same year, government had determined to lay a submarine cable from Gwadur to Fao, the Turkish government having agreed to extend their land lines from Bagdad to Fao, and thus complete the last link in the line of telegraph between Europe and India. It was very wisely determined by government, on the recommendation of Colonel Stewart, that sufficient cable should be provided to admit of a submarine line being constructed the whole distance from Fao to Kurrachee; as, independent of the necessity of providing for any casualty to at least a portion of the cable on its passage round the Cape to India, it was felt that, for various reasons, the Mekran land telegraph between Gwadur and Kurrachee could not be relied on. This precaution was fortunate, as the Mekran line was so wretchedly constructed, that, in spite of a splendid climate for telegraphs, the two wires (owing to innumerable contacts) could only be worked as a single conductor, and even that only when the sun had risen for some time, and thus evaporated the dew. So that it may be said, at the best, to have been but a quarter of a telegraph.

"The late Lieutenant-Colonel Stewart, R.E., was, as director-general of the Indo-European telegraph, entrusted with the general direction of the work, and selection of the staff: for the Persian Gulf line, Messrs. Bright and Clark were engaged as engineers for the supervision of the manufacture and submergence of the cable; and the cable was manufactured at Mr. Henley's works, North Woolwich. The submergence of the cable, and establishment of the stations, were effected under the direction of Lieutenant-Colonel Stewart, who had full authority over all the government ships, staff, etc.; the immediately executive, engineering, and electrical work being carried out under the supervision of Sir C. Bright, and his assistants, Messrs. Laws and F. C. Webb. The line was successfully completed by the 15th of May, 1864; but the Turkish land line, from Bagdad to Fao, owing to political difficulties with the Arab tribes, was not completed until the end of January, 1865.

"The cable is composed of a conductor, weighing 225 lbs. to the nautical mile, insulated with 265 lbs. of gutta-percha, and served with untarred hemp—applied after soaking in salt water—and sheathed with twelve galvanised iron wires of No. 7 Birmingham wire gauge. This sheathing, although galvanised, and weighing 2·90 tons to the mile, is further protected from rust by Mr. Latimer Clark's patented covering of hemp and bitumen, the complete cable weighing 3·75 tons to the nautical mile. The principal features of the whole work consisted in the employment of a conductor formed of five different segments, yet presenting the form of a perfectly solid cylindrical wire: the adoption of an untarred serving, next to the gutta-percha, as experience had proved that small faults in the gutta-percha became sealed up by the Stockholm tar with which the serving of former cables was saturated. This improvement was patented by Mr. Willoughby Smith; but we believe the Persian Gulf cable was the first cable thus manufactured with an untarred serving. The outer serving of bitumen and hemp had not previously been applied on such an extensive length, or on a cable intended for a tropical climate. The cable was also paid out from the five sailing ships which brought the cable out from England, the ships being towed by steamers.

"The attempt to submerge cables from sailing ships in tow of steamers had nearly always previously, even on short lengths, been attended with failure; and the success on a line of such magnitude, and so distant by sea-passage from England, was important, as the expense of carrying a cable weighing 5,000 tons in steamers to such a distance would greatly add to the cost of the line. Thus, the excuse so often made for constructing lines that could not last a year, on account of the expense of carrying out a cable that would be durable, is practically disposed of, at least for any line in shallow water, and where ordinary weather can be counted on. The fitting of the ships and shipment of cables were

performed in detached and sub-contracts, and by time-work, and the cable was laid by the engineers without the slightest intervention of a contractor, thus saving a large sum, whilst the work was done in a thoroughly satisfactory manner.

"The Persian Gulf line, as at first laid, was 1,153 nautical miles in length, and divided into four sections. A heavy shore-end cable, containing two conductors, was eventually laid off Bushire, and the sections terminating there cut at sea, and spliced on to this cable. This alteration and the deviation of the cable from the original eastern termination of the line at Ras Muari to Manora Point, and some minor deviations to avoid rocky ground, made the sections in 1865 as follow:—

	Nau. Miles.
Manora (Kurrachee) to Gwadur .	269·07
Gwadur to Mussendum	359·51
Mussendum to Bushire	396·48
Bushire to Fao	157·73
Total	1182.79

To the necessary arrangements for the working and maintenance of the line, Lieutenant-Colonel Stewart had devoted much time and energy. A complete European staff for working the line, including Dr. Esselbach as general superintendent, Mr. Hirz as electrician, several mechanicians, Mr. Brasher as traffic manager, and two assistants, and a number of English telegraph clerks, were engaged.

"A steamer, fitted with every appliance for repair, was sent out, to be stationed at Kurrachee, where a cable-tank for spare cable had been prepared. Lieutenant Stiffe, who had been previously engaged for many years on surveying duties in the Gulf, was appointed to the command of the repairing-ship, the *Amberwitch.* After the cable was laid, Mr. F. C. Webb (who, as Sir C. Bright's assistant in the engineering department, had been engaged on the work from the commencement) was appointed to remain for one year in engineering charge of the line, so as to maintain the cable, instruct and organise the first engineering staff, and execute certain alterations. During this year the line was repaired in two or three places where it rested on rough ground, and the cable deviated from these patches; the heavy shore end off Bushire was laid, fresh and larger cable-tanks were commenced, and other alterations made. The engineering and electrical staff were thus enabled to gain considerable experience."

Such is the early, and, indeed, comparatively recent, history of telegraphy in India. We must not omit, however, to notice the great exertions made by Sir W. O'Shaugnessey in originating the Indian system. Whatever failings may have since arisen, it was to his determinate endeavours that internal India is indebted for telegraphic communication. In 1855, or 1856, we had several lengthened interviews with him on the subject, and were led to consider, that had he at the time full scope to carry out his views, the results in India itself would have been of the highest advantage. He selected in this country a numerous staff of trained assistants; but it is almost needless to say that the old system of management then prevailed in both civil and governmental departments, leaving real talent unused or snubbed, whilst office and favour rule everything.

It is a matter of surprise that Indian telegraphy, comparatively speaking, made such little progress. As already remarked at a previous page, there are few, if any, parts of the world in which a system of telegraphy, properly arranged and conducted, could be made to pay as well or better. But our East Indian possessions have never had that due attention to the development of their resources as they need and deserve. In fact, they have been, politically and commercially, scarcely out of the leading-strings of infancy. It is more than probable that, if it had not been for the great demand which occurred for cotton subsequent to 1861—owing to the American civil war, that all but stopped our supplies of cotton—Hindostan generally would still have been centuries behind other parts of the world in respect to road, railway, canal, and telegraphic communication: the want of all of which, to a greater or less extent, yet interferes with the export of its productions, and greatly enhances their price. It has already been frequently pointed out how much electric telegraphy has done for our islands in the economisation of capital. But the extent, in length or distance, of Great Britain at its most extreme points, is as nothing compared to India; and the population, similarly, is comparatively insignificant. But it is not to India alone that we must look to find the importance of an extended system of telegraphy in the East. As previously mentioned, our Indian possessions are, as it were, only a "half-way house" to equally important countries. Japan and China, together with the countries (Birmah, etc.) forming the south-east corner of Asia, have a population equal to ten times, at least, of that found either in the British Isles, France, or the United States of America. Consequently, as we open out fresh channels of communication with Eastern India, we find fresh and larger markets for our manufactures; fresh sources of raw material, used by us as food, for manufacturing and other purposes; fresh employment for the operatives of our home islands; and, as a subsequent result, fresh sources of our national prosperity, that so largely depends on the extension of our manufacturing industry, and on our exports and imports. India, in fact, ought, in many senses, to become the "Garden of England."

Such considerations as these eventually led to an extension of the telegraphic system. The political condition of India has at all times required a constant reference to the Home authorities, and speed is an element of the utmost importance in such cases. These, with the commercial reasons just assigned, eventually led to the employment of public and private capital. Without entering into lengthened details, we may sum up the results by stating

that the London morning papers in 1881, daily furnished the previous day's news from Japan, China, all parts of India, Australia, interior southern Asia, and so on to the confines of Europe; and if circumstances specially required it, a message could be sent to Calcutta, etc., and the reply received within the space of half-an-hour.

We next turn to a subject, the Electric Light, etc., which will naturally be of great interest. After this we shall deal with the British Postal-Telegraph system, with which we shall include descriptions, etc., of some astonishing improvements, including the Telephone, Microphone, duplex and quadruplex telegraphy, etc., etc.

CHAPTER XVII.

THE ELECTRIC LIGHT—DYNAMO-ELECTRIC MACHINES—ELECTRIC LAMPS—PHOTOMETRIC VALUE OF THE ELECTRIC LIGHT—ITS COST—ITS APPLICATION TO HORTICULTURE—STORAGE OF ELECTRICITY—ELECTRICITY AS A MOTIVE POWER, ETC.

THE year 1881 will long stand out conspicuous for the astonishing success which was achieved during it in respect to the applications of electricity for the purposes of man. The Electrical Exhibition of that year, held at Paris, actually took even the scientific world by surprise, while the popular element had its curiosity and love of wonder gratified by the brilliant results that science had attained, and applied to numerous purposes of daily life. The heading of this chapter will sufficiently give an idea of the subjects it embraces, and which we shall deal with in the order above indicated.

In the Introduction to this work, and in the first volume, the reader will find a general history of what progress has been made in the application of electricity for the purpose of artificial illumination (see pp. lxxviii. to lxxxiv.) In the preceding chapters on Voltaic Electricity, Electro-magnetic, and Magneto-electric Induction, the science of the whole question has been dealt with in the most minute detail, and we shall assume, therefore, that our readers have become well acquainted with what we may call the philosophy of the Electric Light. Such being the case, it would only become our duty now to enter into a description and illustration of the remarkable success which has followed the application of recent inventions. But as in a higher class of teaching we require "line upon line," etc., so perhaps it may be as well here briefly to point out why former attempts to obtain a steady and useful electric light were baffled, and on the other hand, how it has now achieved so great a success as to make that light a serious rival to gas as an illuminating agent.

The voltaic battery, as we have already pointed out in the chapter on Voltaic Electricity, *et seq.*, is inconstant at the best in its action, and its best forms speedily lose their power, and cease to become of any use for the purpose of illumination. Again, all the old forms of electric lamp were more or less uncertain in their action (see Introduction, pp. lxxix. and lxxx.) Either the machinery was constantly getting out of order; the carbons would not, owing to their inferior quality, burn evenly; or perhaps, when most wanted, would break altogether. In our earlier days, boxwood charcoal was alone employed for them; this was succeeded by points of gas-carbon, but both failed in homogeneity, and were therefore valueless.

It may be interesting, as a matter of history, and as anticipating the improvements of the present day, if the following remarks are reproduced. They were written by the editor of this work toward the close of 1868:—

"One of the most recent improvements that have been brought out, is that described in the following abstract of a paper, read, in 1868, at the ordinary monthly meeting of the St. Andrew's Literary and Philosophical Society, by Professor Swan, entitled 'Recent Improvements on Electric Illumination.' The professor, before describing Foucault's electric regulator, said that he should recall a few of the leading facts in the history of the electric light. For the electric light, produced by the passage of a current of voltaic electricity between certain points, we are indebted to Sir Humphrey Davy, who, soon after the beginning of the present century, by means of a battery of 2,000 copper and zinc elements, belonging to the Royal Institution, obtained, between carbon terminals, a luminous electric arc, four inches in length. The improved voltaic combinations of more recent times enable us to obtain an efficient electric light by more moderate means; while the light to be exhibited by him (Professor Swan) would be obtained by means of a Grove's battery of forty cells. Sir H. Davy discovered that platinum and other refractory metals were readily melted, and, in most cases, consumed, in the intense heat of the electric arc. The light produced by the combustion of mercury had been proposed by Professor Way, for purposes of lighthouse illumination. Way's light was shown by allowing mercury to stream from a glass funnel, with a capillary orifice—one wire from the battery dipping into the funnel, another into a glass phial, into which the mercury ran. A brilliant bluish-white light was thus obtained.

The value of the electric light as a powerful means of illumination, had rendered it an object of importance to devise means for its steady and continuous exhibition. But this was by no means easy of accomplishment. The carbon points are continually wasting by combustion, and the distance between them thus tends to increase, until the current ceases to pass, and the light goes out. Again, if by chance the carbons get into contact, the current, indeed, passes even more freely than before, but merely heats them to a dull red, without producing any effective light. It is necessary, then, for the certain and uniform production of the light, that, by means of appropriate mechanism, the carbons be kept at a nearly constant distance from each other—never separating so far that the current is unable to pass through the interval between them, nor coming into contact. Moreover, if the voltaic arc is employed for purposes of lighthouse illumination, it is absolutely necessary that its position should be fixed. Of the two carbon terminals one is always found to waste much faster than the other, and it is, therefore, necessary to provide that the carbons be moved towards each other with velocities proportionate to their rates of wasting. Professor Swan stated that these conditions were being perfectly fulfilled by the regulator of Serrin, and by the new regulator of Foucault. Foucault, to whom we owe one of the earliest forms of electric regulator, contrived the ingenious automatic arrangement, by which the varying strength of an electro-magnet—formed by the electrical current itself which furnishes the light—is made, by appropriate mechanism, to regulate the distance of the carbons. In Foucault's first regulator, as constructed and improved by Duboscq, there is a train of clock-work wheels, driven by a spring, and controlled by a fly, for causing the carbons to approach each other with a slow, steady motion. So long as the current passes in full force, the electro-magnet attracts a piece of iron, or keeper, which acts upon a detent, preventing the train of wheels from moving, and thus maintaining the carbons immovable; but so soon as, from waste, the distance between the carbons increases, and the light tends to be extinguished—the current becoming feebler—so does the magnetism which it generates. The magnet then allows the keeper, with its attached detent, to fall away, the train is released, and the carbons approach each other, until—the current once more attaining its full strength—the magnet again attracts its keeper, stops the train of wheels, and brings the carbons to rest at a proper distance from each other. The peculiarity of Foucault's new regulator consists in this, that it has two independent clock-work trains—one to cause the carbons to approach, the other to cause them to recede from each other. A balance is kept up between an electro-magnet, formed by the current, which attracts a keeper, and a spring which tends to pull away the keeper from the magnet. Variations in the strength of the current, due to the variations in the distance of the carbons, thus cause the keeper to approach or to recede from the magnet, and to move a lever, whose long arm, furnished at its end with a cross-piece like the head of a hammer or pickaxe, lies between the flies which regulate the motions of the trains, and which are for that end placed close together. When the carbons are at a proper distance to let the current pass, the magnet attracts the keeper just so much that the pickaxe-shaped detent lies equi-distant between the two flies, its extremities reaching far enough to touch both, and thus to keep both trains stopped, and to maintain the carbons at rest. When the waste of the carbons weakens the current, the spring begins to overcome the magnet; the lever, with its pickaxe head, moves to one side, and the point of the pickaxe recedes so far from one of the flies that it is free to move. The train connected with this fly then brings the carbons together, until, the current attaining full strength, the magnet brings back the lever and detent to their first position, both trains are stopped, and the carbons are at rest. But if the carbons are by any chance in contact, or too near to each other, the magnet overcomes the spring, and moves the lever in the opposite direction to its former motion. The detent now releases the other fly which is connected with the train, causing the carbons to separate. The carbons accordingly immediately recede from each other, until—the current falling to its normal strength—the lever comes back to its position for stopping both trains, and the carbons once more come to rest at a suitable distance for the production of the light. The regulator having been placed in a Duboscq lantern, the use of the light in exhibiting physical phenomena was then illustrated by a number of experiments. Among these were the projection, on a white screen, of the image of the ignited carbons and the electric arc itself; the exhibition of specimens in natural history by the solar microscope; the projection on the screen of the phenomena of the decomposition of water; and the formation of a "lead tree" by the decomposition of acetate of lead by voltaic electricity. The prismatic spectrum of the voltaic arc was then projected on the screen, and the bright lines in the spectra of salts of sodium, strontium, and of zinc and other metals were exhibited; the regulator having been removed from the lantern, the electric light was next exhibited alongside of the lime light and the magnesium light. Although hydrogen, and not coal-gas, as is frequently the practice, was used for the lime light, the result of the trial was decidedly in favour of the electric light.

"It unfortunately happens that every new form of electric lamp is described as perfect; but when brought into regular use, its imperfections rapidly appear, and it eventually becomes a matter of history. We have had many forms in use; and, several years ago, had one constructed on very similar principles to that described in the preceding remarks; but, as in prior lamps, a continuity of action for any length of time was impossible.

"The greatest success that has yet been attained is that of Mr. Holmes, whose arrangement is so far perfect as to keep up the light with great constancy. The lamp exhibited by him, in connection with his magneto-electric machine, at the Exhibition, in London, of 1862, and still used by him, is described as follows in the *Jurors' Report* :—"Two cords are wound, in opposite directions, round two portions of one shaft, of unequal diameters. The cord from the larger portion of the axis is led down under a pulley on the frame which carries the upper electrode, and then up to a lever, the functions of which will be presently described. The bight of the cord under the pulley supports the upper electrode, with its frame. Similarly, the cord from the smaller part of the axis is led down under a pulley on the frame carrying the lower electrode, and then up to a pin, which can be turned round by the hand, so as slightly to lengthen or shorten the cord. The bight of the second cord supports the lower frame and electrode. The upper frame would, if unchecked, fall down, unrolling its cord from the larger portion of the shaft, and, consequently, raising the lower frame and electrode. The rise of one, and the fall of the other, take place in the proportion of the diameter of the two parts of the axis. This movement is checked by a detent gearing into a star escapement-wheel. The armature of an electro-magnet frees this wheel when the current falls below a given strength, depending on the adjustment of an antagonistic spring attached to the armature; a continuous feed is thus produced, exactly similar to that obtained by a Duboscq's lamp. The pin already mentioned, by shortening or lengthening the cord of the lower electrode, allows its height to be adjusted with ease and accuracy, so as to bring the light into the exact centre of a reflector or lens, if necessary—a matter of the utmost importance in regard to lighthouse illumination, in which, of course, the light should always be in the axis of the lens or reflector, otherwise it becomes comparatively useless.

"The lever to which one end of the cord of the upper electrode is secured, is so centred that, by slight rocking, it lifts or lowers one end of the cord, and, consequently, the whole frame or electrode. The motion is confined within small limits by stops. A weight on the other end of the rocking lever nearly balances the weight of the upper frame; and an armature attached to this weight hangs immediately over a second electro-magnet. When no current circulates through the lamp, the weight of the frame and electrode overbalances the counterpoise, the armature is lifted from the second electro-magnet, and the end of the lever carrying the cord falls, lowering the upper electrode; but when the current is passing, the armature of this electrode is attracted, and, with the aid of the counterpoise, pulls down one end of the rocking lever, lifting the cord, and, consequently, the upper electrode. The first electro-magnet then works the detent regulating the continuous feed. If the current fail for an instant—if, for instance, the light be blown out—the armature of the second electro-magnet flies up, the upper electrode falls into contact with the lever, re-establishes the current, and again is drawn up to the original distance, so that the lamp is re-lighted."

Such may be considered as a statement of the electric light question up to about the year 1870. It must be borne in mind, however, that for lighthouse illumination, the electric light, produced by Holmes's machine, or its modifications, was in limited use. Occasionally the newspapers announced some "successful" application of the electric light, or some new invention, but the facts of such cases in no case verified their announcement.

In 1870 the British electrical world was mostly interested in the transferrence of the telegraph system to the government from the old companies, and the circumstance called out some new inventions. The production of submarine cables, testing and laying them, for some years afterwards, chiefly engaged the attention of the scientific world, and it was not until some years later, when the electric light was introduced into Paris, that the subject received earnest attention. Since then the labours of Siemens, Gramme, Edison, and a host of other scientific and practical men, have been devoted to the question. The electric light now illumines most of the leading thoroughfares of the City of London, and many in the metropolis, the theatres, music-halls, museums, warehouses, etc., etc., with a steady and brilliant light, and at a cost less than that of gas under favourable circumstances. Attention has been earnestly devoted to its adaptation for private houses. By the power of storage afforded by Faure's arrangement, it is quite possible to deliver from house to house a six or eight hours' supply of electricity for such a purpose, and there is not the slightest exaggeration in stating that at the close of 1881, electricity, for use in lamps, could have been hawked about the streets by itinerant dealers in a similar manner to that adopted in the case of paraffin oil. We may here briefly notice, as a still more astonishing novelty, that Dr. Siemens actually succeeded in growing ripe melons, bananas, and pine-apples solely by the electric light, and, of course, with the entire absence of the light of the sun.

The secret of the great success that has recently attended the attempted applications of electricity is easily explained—a concentration of knowledge and practical skill to the attainment of two objects. We have already stated how much might be done with the old forms of the magneto-electric machine, and that was simply to show that magnetism was capable of inducing an electric current. The following cut illustrates one of the earliest and best forms of these : *a* represents a battery of horse-shoe permanent magnets, before the poles of which revolve the armatures *b b*. These consist of two cores of soft iron covered with a great length of fine covered copper wire, the terminals of which make and break contact with external conducting wires, through a mercury cup or

other arrangement at *c*, the armatures being made to revolve rapidly by the wheel *d*. This instrument may be called the *germ* of the present arrangements. The results it gave in respect to the luminous calorific and other effects were small but decisive, and to increase these in the most effective manner has been the great object. Now, referring to the illustrations of the Lontin machine given at page lxxx., etc., in the Introduction, Vol. I., precisely the same principles are involved, but the details of construction differ. But the most important improvement was that of making a magneto-electric machine of small size, the means of converting large masses of iron into electro-magnets in another. While the machine shown in the preceding figure has little power, it may be made the means of producing electro-magnets of indefinite power in another, and so of dispensing with permanent steel magnets, which, when of the largest size, have little magnetism compared to the electro-magnet. In these machines the magneto-electric current is thus used in place of the voltaic battery. We have seen at page 343, *ante*, what an immense magnetic power can be produced by the voltaic current. But in the modern magneto-electric or dynamic machine no battery is required. Motion may be made to produce an indefinite amount of magnetic force, consequently, the steam-engine, the water-wheel, or windmill, may each and all be now used to drive the modern dynamic machines, and so to afford any amount of electricity, and that constant for an indefinite period. Practically speaking, therefore, the dynamic machine effects the conversion of mechanical power into electric force. The merest tyro to science must therefore perceive that there can be no limit to the electric power thus generated, and could the Falls of Niagara be conveniently utilised, they might possibly supply the electric power sufficient to illumine any number of towns in the United States and a portion of Canada. On the natural scale this is being done on estates where small waterfalls exist, and a little town in England is now being illuminated by the electric light through the utilisation of the mechanical force of a waterfall produced by a river running near it.

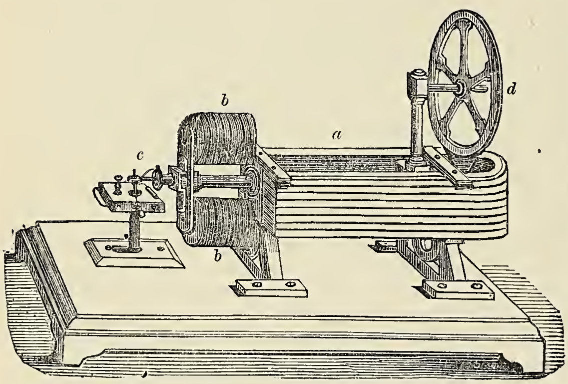


Fig. 283.—Magneto-Electric Machine.

The next great object which has been so successfully accomplished, has been the improvement of the lamps, by means of which the electric force is practically converted into light. The defects of the old forms have already been pointed out at the commencement of this chapter. It was reserved for M. Paul Jablochkoff first to get over this difficulty. He was an engineer officer in the Russian army, and was entrusted in 1869 with some electrical investigations at the Ecole Galvanotechnique of St. Petersburg, and afterwards had under his charge the telegraph lines from Moscow, etc. Towards the close of 1875, he started from Russia to visit the Philadelphia Exhibition, but got no further than Paris, where he entered the establishment of M. Breguet, and on March 23, 1876, he secured his first patent for the electric candle. The electric candle was presented to the Academy of Sciences by the President, M. T. B. Dumas, in the name of M. Denayrouze. On that occasion M. Dumas spoke as follows :—"I have the honour to bring before the notice of the Academy the results of investigations by M. P. Jablochkoff on an invention which has made a great step in the problem of electric lighting. This discovery involves first the suppression of all the mechanism usually employed in ordinary electric lamps. The new luminous source is composed of two carbons fixed parallel to each other, a slight distance apart, and separated by an insulating material which is consumed at the same rate as the carbons themselves. As soon as the current commences to pass, the voltaic arc plays at the free ends of the two carbons. The adjacent insulating material becomes consumed, and slowly uncovers the double ring of carbon just as the wax of a candle uncovers gradually its wick. The invention in question appears to me, at first sight, as a vast simplification in the known processes for the production of the electric light, in suppressing regulating apparatus, and I think the advantages may be summed up as follows :—The heat from the combustion of the carbons lost in the air with regulating lamps is utilised in the Jablochkoff candle for the combustion of the insulating material. The composition of the latter can be varied indefinitely, since a vast number of earthy materials may be used. The most refractory substances volatilise when placed in the voltaic arc, as it is placed by the arrangement of M. Jablochkoff. We have employed as insulating materials, sand, glass, lime, ground brick, etc. But the most simple, as well as the least costly, is a mixture of sand and glass."

This was the first official description of the Jablochkoff candle, and for which we are indebted to the columns of *Engineering*. At page lxxxiv. in the Introduction, Vol. I., there will be found an illustration of this candle, together with a description which explains its construction.

Jablochkoff's candle has undergone many improvements since its first invention. These were abundantly illustrated at the Paris Exhibition of 1881. At first the difficulty of unequal combustion of the points was got over by making the positive carbon twice the size of the

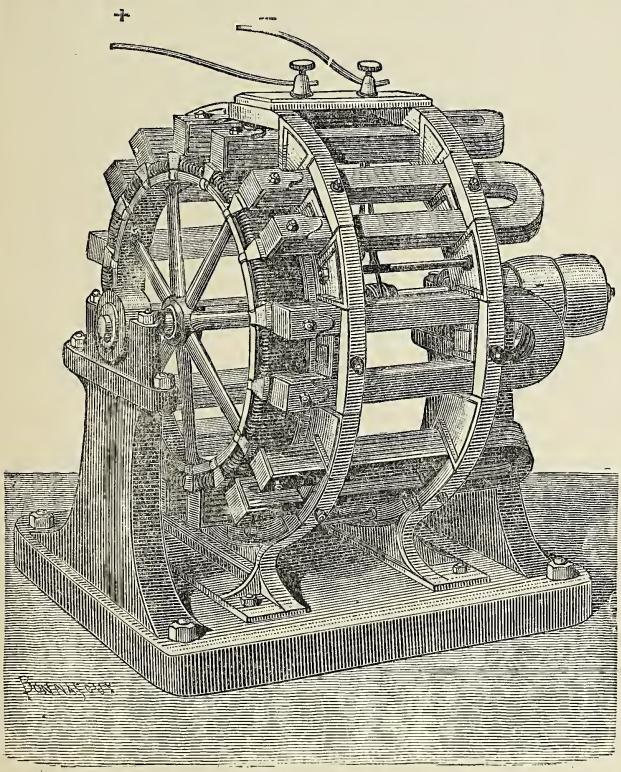


Fig. 284.—De Meritens' Magneto-Electric Machine.

negative carbon. But the ratio was not, however, mathematically correct, and varied according to the quality of the carbon used. But by the use of alternating currents, making successively each point of the carbon a positive and a negative pole, the carbons were consumed in equal quantities in the same time. In the course of five years their price has been reduced to one-tenth of their original cost. The Société Génerale d'Electricité alone consumed in a short period nearly 1,900 miles of these carbons for the electric light. The standard type in respect to size is 0·16 inch in diameter, and at present in France the carbons are generally delivered in sticks $19\frac{1}{2}$ inches long. For the purpose of increasing the duration of the candles while burning, they have been electrotyped externally with copper or nickel. This has the effect of diminishing the resistance of the carbons, and preserving them from contact with the air. There results from this a considerable diminution of the incandescent cone of the carbons, and consequently a slower combustion. The remarkable success of the Jablochkoff candle is due to the extreme simplicity of the device as well as to the absence of mechanism and regulating apparatus.

We next turn to give descriptions and illustrations of some of the most approved forms of dynamo-electric machines now used. That of Lontin has already been described and illustrated in the Introduction, Vol. I., p. lxxx., *et seq.* We are indebted to the columns of *Engineering* for the following description of M. De Meritens' machine, which, as will be seen, forms, by the use of permanent magnets, a kind of connecting link between the early magneto-electric machines described at page 568, *ante*, and dynamo-electric machines now in use.

One of the most interesting and remarkable machines for the induction of electric currents is the magneto-electric machine of M. de Meritens. This apparatus is interesting because it embodies and combines in its construction the principle of action of the early magneto-electric machines of Clarke and Holmes with that of the modern dynamo-electric machines of Gramme and Brush; and it is a remarkable machine on account of its very high efficiency as an apparatus for the conversion of motive power into electricity by induction from a magnetic field produced by permanent magnets, and on this account it stands alone among all magneto-electric machines as being able, with some indications of success, to hold its own for producing the electric light in a field which is otherwise monopolised by dynamo-electric generators.

The distinctive feature of the De Meritens machine lies in the construction of its rotating armature, which, like the Gramme armature, is in the form of a ring, and wound in a similar way; but it differs from it in being made up of a

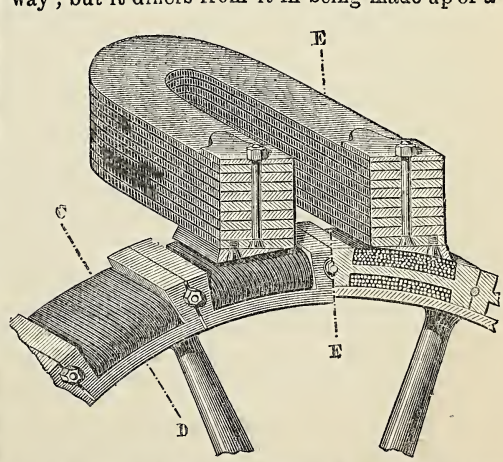


Fig. 285.—De Meritens' Magneto-Electric Machine.

number of segments, each constituting a separate arc-shaped electro-magnet with expanded poles, which are joined end to end with a thickness of insulating material between them, so as to form a continuous ring. It may for the sake of illustration be looked upon as a Gramme armature cut up into a number of short lengths and built up again into a ring, but each length being magnetically insulated from the other. This ring forms the periphery of a wheel, which is mounted on a horizontal spindle, and is thereby rotated in a vertical plane within a crown of compound horseshoe permanent magnets, and just underneath their polar ends, the distances of which from one another are equal to the lengths of the armature segments, which is the same as the pitch of their poles around the ring; and the armature coils, although all wound in the same direction, are so connected up that while the current sent into the external circuit of the machine is alternating in direction, the currents generated in the several parts of the armature are at any one moment all of the same sign, and therefore in no way tend to neutralise one another.

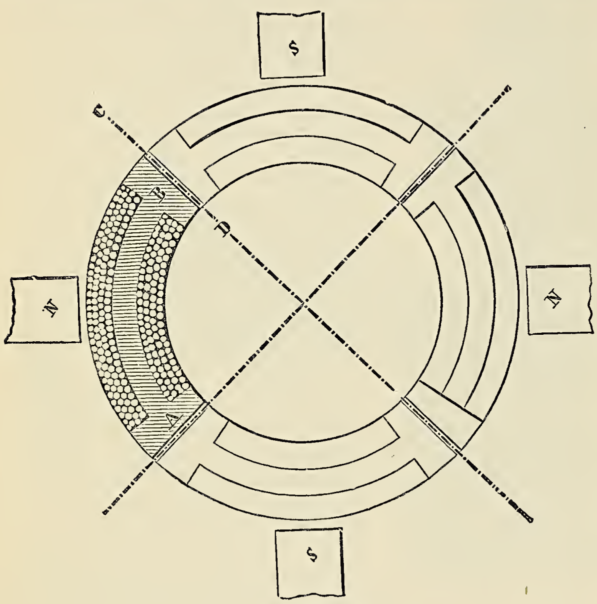


Fig. 286.

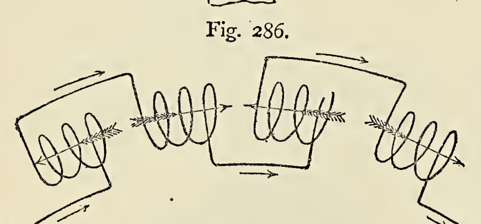


Fig. 287.

In the machines as actually constructed, the magnetic crown or battery consists of eight horseshoe compound permanent magnets, arranged as shown in Fig. 284, and of the construction figured in detail at E, Fig. 285. These magnets are rigidly attached to two circular frames of brass firmly bolted to the base-plate, and within the crown so formed the armature or induction wheel is caused to revolve on a horizontal spindle, and its electro-magnetic inductors are so arranged that their poles in their revolution pass in succession as close as possible to the magnet poles without actually touching them. The cores of the induction helices (see Fig. 285) do not consist of a solid mass of iron, but are composed of a large number of thin laminæ punched out of sheet-iron one millimetre in thickness, and laid flat one upon the other, until a sufficient thickness is obtained. In the machine shown at the Albert Hall Exhibition there were as many as fifty plates or laminæ composing each segment of the armature ring. The advantages of this form of construction are twofold: first, the laminated character of the armature cores assists their rapid magnetisation and demagnetisation, breaking up and otherwise preventing cross currents by which their magnetic capacity is reduced; and, second, the building up of the cores by means of superposed plates of the shape of its longitudinal section offers great facilities for construction. While each segment of the ring is thus built up, the ring itself is, as we have before pointed out, also compound, as will be seen by reference to Fig. 285. The segments after having been wound with insulated wire are arranged end to end around a brass wheel, with strips of copper between them, so as to break up the magnetic continuity of the ring, making each segment a complete and separate magnetic inductor, and they are firmly held in their places and together by a bolt passing through each joint, which is tightened up by a nut, as is shown on the diagram. The advantages of this method of construction are obvious to any one who can appreciate the slow and inconvenient process of winding a Gramme ring, which, being a continuous circle, can only be covered with wire by hand, the spool containing the wire to be wound having to be passed over and back through the ring for each convolution of the wire. By making the ring in segments, however, no such tediousness is experienced, for each piece can be put in a lathe and wound as an ordinary coil, and when so wound all can be joined up together with insulating pieces between them—a method of construction possessing especial advantages both electrically and constructively.

The action of the apparatus can best be understood by imagining an extremely simple case of a machine (illustrated in the diagram, Fig. 286), having an armature ring built up of only four segments, one of which is shown in section

marked A B, and revolving within the magnetic field of two horseshoe magnets, N S, N S, placed with their poles at equal distances around the ring, and so disposed that any point in the ring will during its revolution pass them in succession, assuming thereby alternately north and south polarity.

The expansion of the poles A and B, so as to become flush with the exterior surface of the fully-wound coil, besides facilitating the operation of winding, plays a still more important part, and it is to this that a great proportion of the high efficiency of the machine must be attributed. By this construction, which is also taken advantage of in the very beautiful dynamo-electric machine of Mr. Brush, the iron of the cores of the several segments of the ring is brought at its polar extremities into very close approximation to the inducing magnets N S in its passage beneath them, and it is for that reason in the best possible condition for being influenced in passing through their magnetic field.

The action of the machine illustrates, perhaps more clearly than any other apparatus, the principle of that group of phenomena which is known as Lenz's law. Thus, supposing the armature to be rotating in the direction of the hands of a watch, the pole piece A approaching the north pole N of the permanent magnet will cause an electric current to be induced in the coil A B in a certain direction, while the opposite pole piece B will, in receding from the same magnet pole N, cause the induction of a current in the coil A B, in the same direction as is produced by the approach of the pole piece A; the two effects are, therefore, superposed or rather added together, and at the same time the current is still further increased by the convolutions of the coil of the same core passing from left to right through the magnetic field of the magnet N. As the coils of all the segments are wound in the same direction, it follows that the next segment which passes below a south pole at the same moment as the segment A B is passing below a north pole, will have induced in its helix a current of electricity in the reverse direction to that developed in A B, which would be opposed to that current, and would, therefore, neutralise it, were it not for the fact that the successive coils are connected together in the manner shown in the diagram, Fig. 302; that is to say, the outside end of one helix is connected to the outside end of the coil which is in front of it, while its inside end is connected to the inside end of the coil which is behind it, from which construction it follows, as will be seen in the diagram, that although the currents induced in any two contiguous helices are opposite to one another in direction, the several helices are so connected together that the alternating currents transmitted into the external circuit by each of the coils are all at any one moment in the same direction; in other words, they are all, so to speak, either pulling or pushing together. The two ends of the entire circuit of all the electro-magnetic helices (which is not, as in the armatures of Gramme, Siemens, and Wallace-Farmer), closed within the machine, are connected respectively to two disc wheels of copper attached to the axis of the machine and revolving with it, but insulated from one another, and upon these wheels stout copper collectors or rubbers are maintained with a certain frictional pressure, and are connected to the two terminal screws of the machine. By this arrangement all commutators are dispensed with, and the construction of the apparatus is thereby much simplified. By variations in the method of coupling up the helices of the armature they may be connected in series, or more or less in parallel circuit, or may be grouped in combinations of the two, and by this means the character of the current generated by the machine may be determined for the work to which it is intended to be applied.

The inventor states, and his statement is backed up by the Comte du Moncel, that by this machine as many as three Jablochkoff candles (see *ante*, p. 568) can be maintained burning steadily with an expenditure of motive power of not more than one horse power, and without appreciably heating its armature or its coils when running at a speed of 700 revolutions per minute; but there does not appear to have been any photometric measurement taken by which the luminous intensity of the candles so illuminated may be compared with the light emitted by the same candles illuminated with the Jablochkoff system. M. de Meritens has, however, invented a candle of his own, which differs from the ordinary Jablochkoff bougie only in having a thinner carbon pencil placed between the other two, from which it is insulated in much the same way as in M. Jablochkoff's arrangement. The two outer carbons are connected to the machine, and the arc passes between them, the intermediate carbon acting merely as a bridge or stepping-stone to enable the current to pass across under variations of strength. M. de Meritens claims for this form of construction the merit of greater steadiness of the light. It is, however, but fair to state that candles of this identical form were constructed and worked by M. Nysten some time ago.

Messrs. Siemens have long been identified with the progress of electricity in its applications for telegraphic and other purposes, and the sudden interest that was excited by the effects produced by dynamo-electric machines induced them to devote their attention to the manufacture. We are indebted to the columns of *Engineering* for the following illustrations, and most of the explanatory remarks.

The most remarkable characteristic of the Siemens machine is its extraordinarily small size and weight in proportion to its power, and nothing shows more strikingly the great advances that have been made in the construction of machinery for the induction of electric currents, during the last twenty years, than a comparison between Holmes's machine (see *ante*, p. 567), which was first used at the Dungeness lighthouse, and the modern Siemens dynamo-electric apparatus, which is installed at

the twin lighthouses on the Lizard promontory; thus while the Dungeness machine occupied no less than 484 cubic feet, the Siemens machine takes up but little over $4\frac{1}{4}$ cubic feet, and the

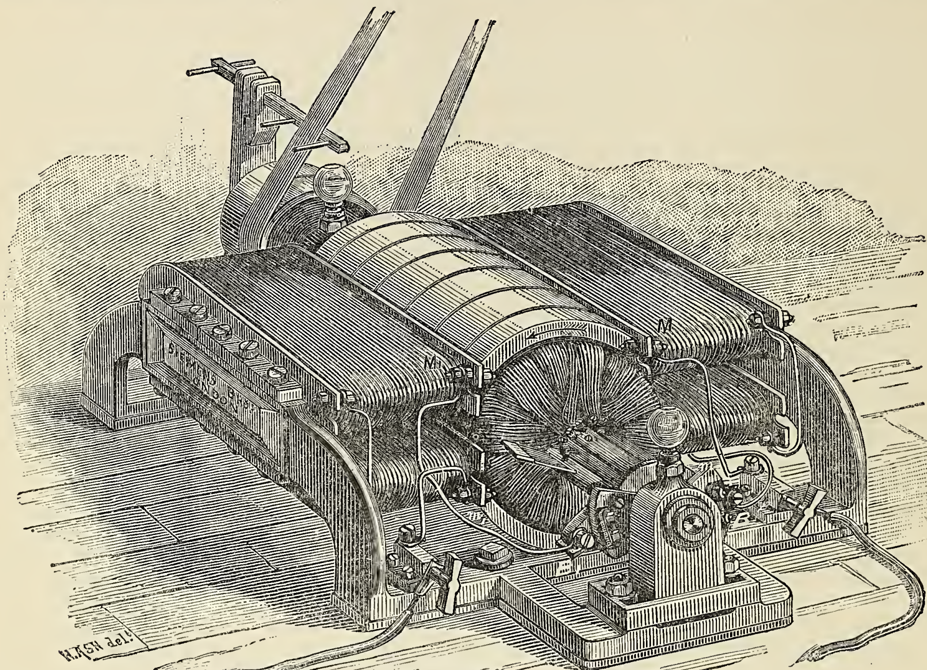


Fig. 288.—Perspective view of Siemens' Dynamo-Electric Machine.

corresponding weights of the two machines are $5\frac{1}{4}$ tons for the Holmes, to $3\frac{3}{4}$ cwt. for the Siemens. Again, while the Holmes machine produced a light equal to 670 candles, the light

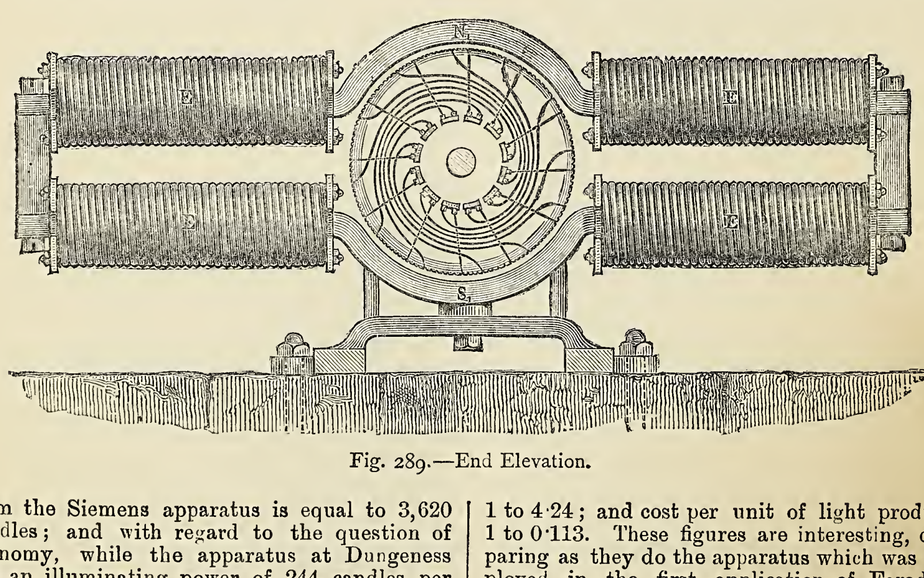


Fig. 289.—End Elevation.

from the Siemens apparatus is equal to 3,620 candles; and with regard to the question of economy, while the apparatus at Dungeness had an illuminating power of 244 candles per horse power absorbed, that of the Lizard machine is 1,034, and the cost of working per unit of light is 0·1294, at Dungeness, to 0·0147 at the Lizard. We have thus the following proportions between the apparatus at the two stations of Dungeness and the Lizard respectively: bulk 114 to 1; weight 28 to 1; light produced 1 to 5·4; light produced per horse power 1 to 4·24; and cost per unit of light produced 1 to 0·113. These figures are interesting, comparing as they do the apparatus which was employed in the first application of Faraday's

transcendent discovery to the illumination of the coast, with the latest and most perfect apparatus which modern science has developed from that discovery.

When part of a closed electrical circuit is caused to move within a magnetic field, so as to cut through the lines of magnetic force in a path more or less perpendicular to their direction, a current of electricity is induced in the circuit, the strength of which depends upon the combination of a variety of causes, of which the principal are the intensity of the magnetic field,

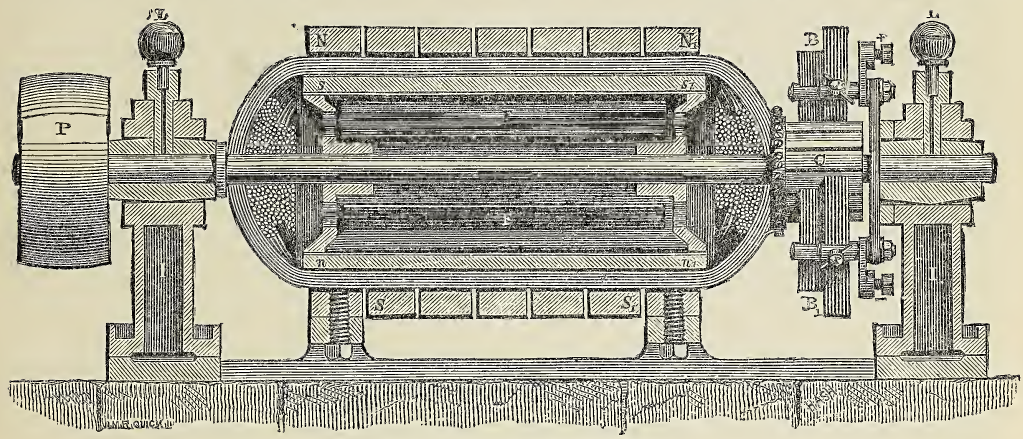


Fig. 290.—Longitudinal Section.

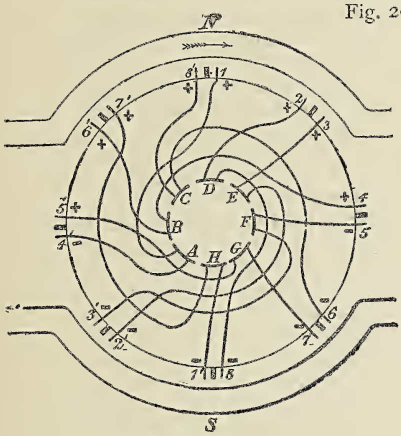


Fig. 291.

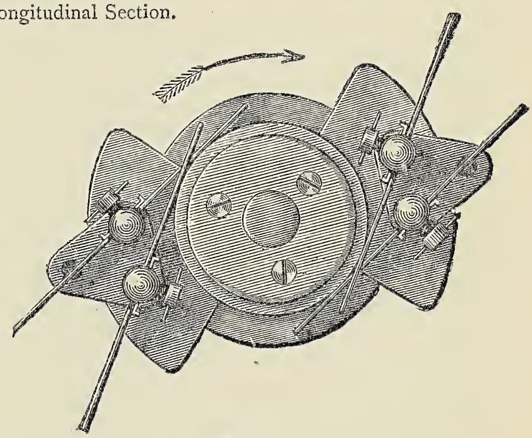


Fig. 293.

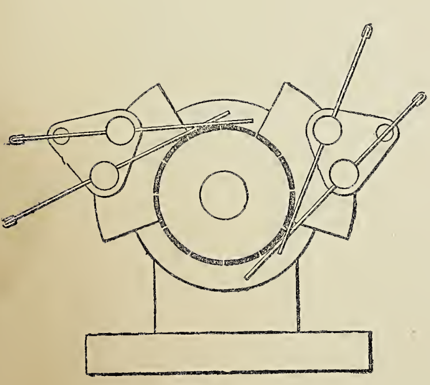


Fig. 292.

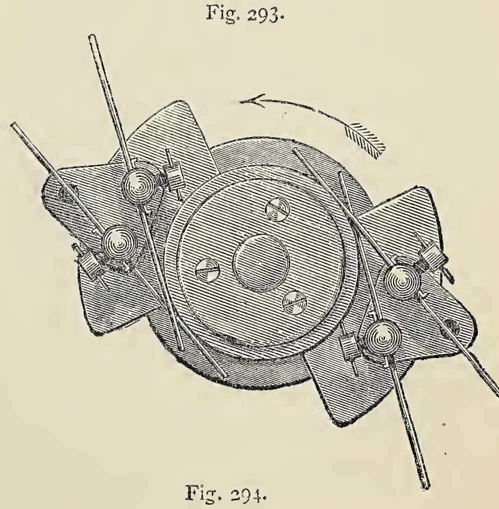


Fig. 294.

and the favourable presentation to its inductive influence of those parts of the circuit which are moving within it. All mechanical generators of dynamic-electricity, whether their currents be induced from permanent magnets, or from electro-magnets, or from a magnetic field excited by their own currents, depend for their action upon the great principle first discovered by Faraday, and investigated so fruitfully by Ampère, Arago, Lenz, and others, and the efficiency of all such machines is determined by the perfection with which these laws and the forces which depend on them are economised. A perfect machine would be one which, producing a magnetic field of the greatest possible intensity or power, is so constructed as to cause a large number of convolutions of insulated wire, forming a circuit, to move rapidly within that field in such a manner as to be always cutting through the lines of magnetic force to the best possible advantage for magneto-electric induction, its length being so proportioned to its conductivity as to present the largest number of convolutions to the inductive influence of the magnetic field without diminishing the strength of the current by unnecessary resistance; and it is just this degree with which the theoretical requirements are fulfilled that constitutes the efficiency of the machine. Up to the present time, the apparatus which approaches that ideal standard most closely is the Siemens dynamo-electric machine, or Hefner Alteneck machine, as it is sometimes called; an apparatus which the experiments of Dr. Hopkinson, F.R.S., show to be capable of converting mechanical power into electricity with a loss of energy of about 13 per cent. That is to say, 87 per cent. of the power exerted on the driving shaft of the apparatus is converted by it into energy of electricity, a transformation of one form of energy into another with an exceptionally high efficiency.

With this explanatory remark we give the following description of the machine which eminently fulfils the conditions thus stated.

The Siemens machine, which is illustrated in the preceding figures, was first publicly exhibited in this country at the Loan Collection of Scientific Apparatus, which was held at South Kensington in the year 1876, and attracted very considerable attention on account of its almost absurdly small size (standing but 9 inches from the ground), and producing a light which far exceeded in power that developed by its much larger competitors. Fig. 288 is a perspective view of the machine, Fig. 289 is an end elevation with the front framing removed, so as to show its principal working parts, and Fig. 290 is a longitudinal section taken in a vertical plane close to its axis of rotation.

The moving conductor in which the electric current is induced by the action of the machine consists of a great length of insulated copper wire wound longitudinally over a cylindrical core of soft iron in several lengths, the number of which depends upon the size of the machine and the purpose for which it is designed. These longitudinal coils of wire completely envelop the iron cylinder or armature, each section being wound parallel to a different plane passing longitudinally through the axis of the cylinder, there being as many of such planes as there are sections to be wound, and at equal angular distances from one another around the circumference of the cylinder. The ends of these coils are connected to a number of copper sectors insulated from one another, which together build up a cylindrical commutator C, Fig. 290, very like that of the Gramme machine, and rigidly attached to the armature spindle with which it revolves; and the currents are collected in a similar manner by conducting brushes B and B, pressing against the commutator as it revolves. This system consisting of the iron cylinder with its enveloping coils, is rotated at a high velocity within a powerful magnetic field produced by a series of electro-magnets, the coils of which are included in the circuit of the rotating armature through the brushes, and are magnetised thereby. The curved bars shown at N_1 S_1, Figs. 289 and 290, are of soft iron of rectangular section, and are the prolongation of the cores of the powerful electro-magnets E E E E, the coils of which are long flat bobbins wound with insulated wire, which are best shown in the general view, Fig. 303. Upon reference to Figs. 288 and 289, it will be seen that the magnet cores, instead of being flat continuous plates, are divided longitudinally into several bars having air spaces between them, the object of which is, firstly, to prevent cross currents being induced in the magnets; secondly, to maintain the lines of magnetic force parallel to the length of the bar; thirdly, to permit of a circulation and escape of air between the revolving armature and the magnets, so as to reduce the accumulative heating of the machine; and lastly, for convenience of manufacture. Of the curved portions of the magnetic cores N_1 S_1, Fig. 289, each surrounds two-sixths of the entire circumference of the induction cylinder so that two-thirds of it are embraced by the magnets, and the coils E E of each set of magnets are so wound as to produce a consequent point or pole in the centre of their length, a north consequent pole being produced in the upper set of magnets at N_1, Fig. 289, and a south consequent pole being produced in the lower set of magnets at S_1. Thus a very intense magnetic field is formed within the cylindrical space included between the upper and lower sets of magnet bars, and within this space is revolved at a high velocity the induction cylinder or armature which has been described.

The action of the apparatus is as follows: When the machine is set in motion by means of a belt driven by a steam-engine or other motor, the permanent or residual magnetism within the magnet cores, aided by the inductive effects of terrestrial magnetism, induces in the wire on the revolving armature a current of electricity feeble at first, but sufficiently strong to increase the magnetic intensity of the electro-magnets by traversing their coils, to which it is led by the collecting brushes and external circuit of the machine; the effect of this is to increase the intensity of the magnetic field, and therefore to

induce a stronger current in the coils of the armature revolving within it; this, being transmitted through the magnet coils, still further increases the magnetism of the cores, adding to the intensity of the magnetic field, and so once more increasing the strength of the induced current, which thus becomes stronger and stronger as the armature is rotated, the increase of strength of the magnetic field being only limited by the point of magnetic saturation of the soft iron magnets.

The maximum inductive effect of the magnets upon any one coil of wire on the armature cylinder is when the medial plane of the coil coincides with the plane passing through the poles N_1 S_1 of the magnets, and the minimum effect is produced when it lies in a plane perpendicular to that. The ends of the armature coils are so connected to the sectors of the commutator, and the collecting brushes are so placed with regard to it, that they take off the currents generated by the machine at the position of maximum effect, and as that position gives the last spark, at the commutator, the absence of "sparking" is an indication that the machine is working at its greatest efficiency.

Simple as is the winding of the armature cylinder, the connecting up of the ends of its coils is not so easy to explain even with the aid of diagrams. The attachment of the ends of the coils to the sectors of the commutator is partly shown in Fig. 289, and more clearly in Fig. 291, in which, for the sake of simplicity, an armature of only eight coils is shown, there being the same number of commutator plates. In the diagram the two ends of the same coil are numbered 1 and 1^1, 2 and 2^1, and they are connected to the sectors of the central commutator in the order shown. If these connections be traced, it will be seen that all the coils are united into a continuous circuit, the commutator sectors being traversed in succession, and the signs plus and minus indicate the direction of the current induced at any particular spot in the position of rotation shown in the diagram.

There is to every machine of this construction one position for the brushes to bear upon the commutator in which the current is strongest, and where sparking is reduced to a minimum, and, in order to facilitate the adjustment of the brushes to this position, they are mounted upon a frame, shown edgeways in Fig. 290, and endways in Fig. 292, which is capable of being moved through a certain angular distance around the principal axis of the machine. By this means the position of the brushes at which sparks disappear at the commutator, or are reduced to a minimum, is very readily determined, and the frame being fixed in that position by set screws, the adjustment of the apparatus is complete. The brushes are in two pairs, so fixed that one brush of each pair is slightly in advance of its fellow (see Figs. 290 and 292), the object of which is to render the current more uniform by preventing the occurrence of a break in the circuit, and causing one brush to compensate for any imperfect contact of the other; and the brush-holders are so constructed as to permit of the machine being driven in the reverse direction, it being only necessary to take out the brushes and to reverse them, so that their ends which bear upon the commutator point in the direction of its rotation. Figs. 293 and 294 illustrate the position of the brushes when the machine is driven to the right or the left respectively.

The only wearing parts of both the Siemens and the Gramme machines are the brushes and the commutator, which are not only always rubbing together, but are subject to be more or less burnt under the influence of the current when sparking is taking place. The renewal of the brushes is a matter of only a few minutes, involving a very trifling cost, but the renewal of the commutator was, until the later improvements made by Messrs. Siemens, a much more serious business, and could only be done by the maker, and at considerable cost of time and money. In the Siemens machine, however, as now constructed, each sector of the commutator cylinder is separate and renewable, being fixed in its place by a single screw; by this means the removal and renewal of any one plate, or even, if necessary, of the whole commutator, is a very simple and insignificant matter, occupying only a few minutes, instead of several days, as was the case with the old form of the apparatus. The Siemens machine is that which is employed for the electric lighting of the Albert Hall, where there are five machines fixed in the engine-room behind the organ, which supply the light to five Siemens lamps suspended from the centre of the dome, and surmounted by gilt reflectors, which mix with the pure white light from the electric arc a reflected glow of a warmer tint.

One of the most perfect installations of the electric light, however, that have up to the present time been made is the splendid electrical station at the Lizard lighthouses, where there are six of the medium size Siemens machines, each capable of producing a light of 3,620 candles, and arranged in three pairs. When the weather is fairly clear the lighthouses are illuminated by the currents from one pair of machines, one machine being connected to each lantern, and a second pair of machines is kept in readiness with their engine fire banked up in case of heavy weather coming on or to provide against accidents. Upon the occurrence of thick weather, the second engine is started, when the combined current of each pair of machines is sent to each tower, giving a mean intensity at the focus of each optical apparatus of 8,250 candles, the third engine with its pair of machines being kept ready to start at a moment's notice in case of a breakdown.

The cables which conduct the currents from the machines to the lamps—a distance of 300 feet—are constructed of nineteen copper wires of high conductivity covered with three layers of protecting and insulating material, the first being of felt, the second india-rubber, and the third cotton tape saturated with a solution of caoutchouc wound spirally round the

cable. The lamps, of which there are three pairs, one pair for each lantern, and one pair in reserve, are of the large improved type of Messrs. Siemens.

Besides its application to lighthouses, the Siemens machine is now very largely employed for the illumination of factories, public buildings, streets, etc.; the British Museum reading-room (perhaps the most crucial test of its value), and for the carrying on of works at night; it shares with the Gramme machine the work of exciting the distributing machines with which the streets of Paris are now being illuminated under the Jablochkoff system.

We have already described some of the most important of the modern forms of dynamo-electric machines, including Lontin, De Meritens, Siemens, and incidentally that of Gramme. Before passing on to mention other plans that have been invented, and are more or less in general use, we may refer to the various sources of motive power employed for setting the generating machines in motion, and to describe some of the special mechanical motors by which those sources of power are made to do the work of forcing induction circuits or coils through powerful magnetic fields, which action is the one general *modus operandi* of all dynamo-electric or magneto-electric generators. We are indebted to the columns of *Engineering* for the following remarks on this important and interesting subject.

The various dynamical powers of nature, such as solar heat, gravitation, planetary motion, muscular energy, and gaseous activity, may all, either singly or combined, be utilised for the production of mechanical motion, by which all mechanical operations may be performed, and may, therefore, be employed for the production of the electric light. Of these, the first, gravitation may be divided into terrestrial and extra-terrestrial gravitation, and planetary motion may be similarly divided. Muscular energy may be separated into manual labour and animal power, and under the head of gaseous activity may be classed the active principle in all forms of heat engines as well as the power of the wind. By a combination of solar heat and gravitation, water power is developed, and by combining both kinds of gravitation with planetary motion, the power of the tides is brought into existence, and it is a curious fact that all the powers of nature which are at the present moment utilised for the production of mechanical motion may be traced for a considerable portion of their origin directly or indirectly to the sun. The power of the oceanic tide might be looked upon as an exception, inasmuch as tidal phenomena must be attributed chiefly to the gravitation of the moon combined with the axial rotation of the earth and the orbital motion of her satellite, but it must not be forgotten that the great difference between high range of tide and low, is almost exclusively due to the sun, for the question whether tides are neap or spring is determined by the question whether the gravitation of the sun is opposed to or in conjunction with that of the moon.

With the exception of tidal power all the available powers of nature may be looked upon as species of fuel, which may be traced back for its origin to solar energy. The power of the wind by which grinding and pumping operations are performed, and by which millions of tons are transported across the ocean from one part of the earth's surface to another, is the direct result of solar heat and planetary motion. Again, water power, by which an elevated lake becomes a source of potential energy and by which streams and waterfalls may be made to perform gigantic operations, is directly attributable to solar evaporation lifting the water from the ocean, solar heat producing the winds transporting that water over the land, and terrestrial gravitation returning it to the ocean again, doing work in its path. A water-mill may in this sense be compared to a clock driven by a descending weight which is wound up by the sun. Muscular energy is not so directly traceable to solar activity, but that it is derived from the sun admits of but very little doubt. The food absorbed by the animal system is fuel, which, after being manipulated in the physiological processes of digestion and circulation, is oxidised or burnt in the process of respiration, whereby oxygen is introduced into the lungs, which may be looked upon as a slow combustion furnace producing heat which is convertible into muscular energy. The food by which the combustion in the lungs is kept up, has stored up in it solar energy, the effect of solar radiation pouring upon vegetation in bygone times, which vegetation is directly converted into fuel in plant-eating animals, and indirectly into combustible material in flesh-feeding animals, through the intermediate conversion of the digestive system of the animals on which they feed.

All heat engines depend for their action on the production of gaseous activity, or pressure, by the action of heat, and whether their source of energy be derived from the vaporisation of water and other volatile substances in a closed chamber, as in the case of the steam engine, ether engines, etc., from the expansion of air, as in a hot air or caloric motor, from the rapid oxidation or sudden combination of the constituents of explosive mixtures, as in gas and petroleum engines, as well as the still more sudden effects of the explosion of gunpowder, gun-cotton, dynamite, and similar substances, solar radiation may be accountable in the original instance for the energy produced. Instances of the direct conversion of solar radiation into mechanical power may be cited in Mr. Ericsson's solar engine (alluded in our first volume), and in the steam pumping engine of M. Mouchot, which was exhibited in operation in the grounds of the Paris Exhibition, the boiler of which was heated by solar heat concentrated upon it by an enormous silvered reflector of conical form.

The motive powers which have up to the present time been employed for driving dynamo-electric machines are animal power utilised in hand gear and horse-wheels, water power applied

Thomas Alva Edison.

through turbines and water-wheels, and heat motors such as steam engines, gas engines, petroleum engines, and hot-air engines. We have not yet heard of the application of either tidal energy or the power of the wind for this purpose, but either might be applied with advantage in special situations. There are at the present moment several instances of electric illumination where the motive power is derived from a waterfall at a distance, as well as cases where the machines are driven by horse-wheels. Hot-air engines are employed at the Lizard lighthouses for driving the Siemens machines at that magnificent electrical station, the special form employed being that known as Browne's caloric engine. Petroleum engines are used in America for driving electric lighting apparatus, and Dr. Draper, whose name will ever be famous for his discovery of the presence of oxygen in the sun, employed one of Brayton's petroleum motors for driving his Gramme machine, and he found that he could obtain with it a speed uniform to 1 per cent. of the number of revolutions. The use of petroleum engines, however, is as yet only in an experimental stage.

By far the largest proportion of dynamo-electric machines which are at the present moment applied to electric illumination are driven either by steam engines or by gas engines, and the extension of the electric light has given an enormous impulse to the manufacture of the latter motors. Gas engines are especially well adapted for this kind of work on account of their being able to be started at a moment's notice and stopped as quickly, thereby avoiding the expense of time and fuel necessitated by the getting up of steam in ordinary steam boilers. In cases where a light may be wanted suddenly, and at odd times, or only for short intervals, there is no motor so convenient as a gas engine, and a very large number of lighting machines are driven by the very beautiful "Otto silent" gas engine of Messrs. Crossley Brothers, which has been described in the first volume, and a gas engine, the invention of Mr. Dugald Clerk, has lately been introduced by Messrs. Thomson, Sterne, and Co., which gives the most promising results.

Of steam engines, agricultural portable engines are generally employed for temporary work, such as the carrying on of public works, building operations, etc., by night, or for any special illumination, lasting only a comparatively short time. For permanent stations, however, fixed steam engines are employed, of which any type is applicable, provided it is regular in its speed and steady in its action.

One of the most convenient forms of motor for dynamo-electric work is the well-known three cylinder engine of Mr. Peter Brotherhood. It consists generally of three steam cylinders arranged radially around a framing at equal angular distances apart, their axes converging to a point; within the central space around this point revolves a crank axle, which is kept in rotation by the successive impulse of the three pistons which are connected to its crank-pin by connecting rods, the heads of which are provided with brasses bearing against it; and a circular distributing valve revolving with the shaft regulates the admission of steam to each cylinder in succession, and determines the position of the cut-off, and therefore the period during which each cylinder is being worked by the expansive force of its imprisoned steam. Since Mr. Brotherhood's was first brought out he has very considerably improved it, and for the purpose of driving dynamo-electric light machines it is now hardly excelled if equalled in respect to compactness, steadiness, and uniformity of speed, which last is the all-important requirement of a motor for lighting purposes. The uniformity of speed is partly due to a very beautiful governor, which by actuating a regulating steam admission valve, keeps the engine running with extraordinary regularity of speed.

Of course all makers of fast engines, especially of the portable class used for agricultural purposes, turned their attention to the construction of engines suitable for working the dynamo-electric machine. In the Paris Exhibition of 1881, a great variety of these were employed, and their number of course forbids us mentioning the name of the makers, or the peculiarity of the engines. As already stated, the suitability of a steam-engine for such purposes depends not on the power, because that is a condition easily controlled, but on the steadiness of its supplying a certain number of revolutions per minute.

We are compelled also to omit descriptions and illustrations of other forms of dynamo-electric machines, which are rapidly becoming legion in number. Among such may be named the following:—The Brush, Maxim's, Crompton's, Henrich's, Bürgin's, Edison's, etc., etc.

In regard to lamps, we must also omit mention of the many that have been invented. One novelty we must briefly describe. It is the Incandescent Light of Werdeman, Andre, Swan, and others. In the lamps hitherto described, an arc of light extends between the two carbons. In the incandescent lamp a thin thread of carbon is kept in a highly heated state, so as to afford a continuous white light. This form had been anticipated long ago in attempts to keep a platinum wire constantly at a white heat by means of the electric current. But from various causes the latter plan failed, while it seems probable that the new incandescent lamp will succeed. It would be especially valuable for use in houses in place of gas, in coal-mines, and other places of small area, and requiring moderate illumination.

In regard to full descriptions of dynamo-electric machines, lamps, and other cognate matters, we may refer our readers to the volumes of *Engineering* for 1879-80-81. The volumes for 1881 contain an exhaustive description of the Paris Electrical Exhibition of that year, together with excellently engraved illustrations, diagrams, tables, etc., which present a complete *résumé* of all the applications of electricity that we have mentioned in the preceding pages.

Toward the close of 1881, the use of the electric light was steadily progressing in all

directions in its application in buildings of large area. In London some of the chief thoroughfares were constantly lighted by it, some theatres, the reading-room, etc., of the British Museum, portions of the South Kensington Museum (of which we shall speak hereafter), factories, drapers' shops, warehouses, etc., etc.

The directors of railways saw the advantages which the electric light afforded, and most of the London termini had the gas replaced by the electric light. Some of these are of enormous area.

By reason of its combined power and beauty, the electric light was early recognised to be peculiarly adapted for the illumination of railway termini ; and the first application of it for that purpose was at the Northern Station in Paris, in 1875. There the superiority of the light over gas was found to expedite the business of the station, and the innovation thus begun soon spread to other stations, not only in France, but other countries. In Great Britain one of the most important installations was that at St. Enoch's Station, Glasgow, and the success there attained by Mr. Crompton has since been followed by the lighting of the King's Cross terminus of the Great Northern Railway in Euston-road by a similar arrangement.

The usually large area and high roof of a railway station is favourable to electric lighting by means of powerful arc lamps, for these can be suspended at such a height that the strong shadows they would otherwise throw upon the platform are dissipated, and the blending of the several lights produces a very constant general effect. At King's Cross the space which is lighted within the station consists of two covered ways each 880 feet long by 105 feet wide, together with a cab-rank, 40 feet wide, adjoining the arrival platform. The total area is therefore 220,000 square feet, and as it is illuminated by twelve Crompton lamps, the area lighted by each arc is 18,333 square feet, or nearly half an acre. Six of the lamps are placed above the arrival platform, and six above the departure platform, while two others of greater power are mounted on the outside of the building at the extreme corners of its front to illuminate the side carriage-ways. These fourteen splendid lights are fed by the currents from five Bürgin dynamo-electric machines, driven by a steam engine of 12-horse power nominal.

At St. Enoch's, Glasgow, an area 525 feet long by 203 feet wide is lighted by six Crompton lamps fed by six Gramme machines of the A type ; but the Bürgin machine employed at King's Cross confers several advantages on the later installation. When the Gramme or the Siemens generator is used, only one lamp can be placed in the circuit of each machine, and though this arrangement insures that the failure of a single lamp will not affect the others in the series, it involves considerable expense for plant and leading wires. With the Brush generator from five to forty lamps can be supplied by one machine, and the percentage of useful lighting effect is much higher than with the single-light Gramme system ; but as all the lamps are connected in one circuit, a fault in any part of it, through defective insulation, or derangement of the apparatus, is necessarily followed by the extinction of all the lights. The arrangement at King's Cross occupies an intermediate position between the Gramme and Brush systems, and unites some of the merits of both. Each Bürgin machine feeds three or four Crompton lamps connected in series ; and the total illumination is produced by combining two or more circuits together so that alternate lamps are fed from different machines. By following this plan the failure of any one circuit only reduces the intensity of the general light one-half, since the lamps in the other circuit are still unaffected.

The electro-magnets of the Bürgin machine can either be separately excited by the current from an auxiliary continuous current machine, or they can be self-excited by the current from the armature. In this case the magnet coils are connected in circuit with the armature coils by suitable terminals ; and the total internal resistance of the machine is then 2.8 ohms, or 1.2 ohms for the magnets added to 1.6 ohms for the armature. By separately exciting the machine the internal resistance of the machine is simply the 1·6 ohms due to the armature, and hence a higher electro-motive force can be obtained. The machines employed at King's Cross terminus are, therefore, separately excited by Gramme machines of the A type. There are five Bürgin generators, and two Gramme machines suffice to excite them, besides feeding several Swan incandescent lamps of the pattern tried in the Pleasby mines, which serve to light the engine-room. The exciting current is about 12 webers.

The whole of these seven dynamo-electric machines are driven from a short length of counter-shafting by a semi-portable engine constructed according to Mr. Crompton's designs by Messrs. Marshall, Sons, and Co., of Gainsborough, and similar to that supplied by them to Messrs. Crompton and Co. for the Electrical Exhibition. This engine has a 12-inch cylinder and a 14-inch stroke. Its nominal horse-power is 12, but it is capable of working up to 35 horse power, and at King's Cross, when all the lamps are burning, it is found to indicate 29 horse power, of which $3\frac{1}{2}$ horse power is absorbed by the engine and gearing. Each of the 12 lights within the station absorbs about $1\frac{1}{2}$ horse power, and each of the two external lights on the station front, some 3 horse power. The five Swan lamps in the engine shed are estimated to absorb about $1\frac{1}{4}$ horse power.

The shed where the generators are placed is situated at a distance of about 250 yards from the nearest point of the station, so that the leading wires are of considerable length. The longest circuit of the internal lamps is about 600 yards, and that for the furthest external lamps 700 yards, including the return wire. The twelve lights within the station are strung on four separate circuits, three to each circuit, and the two external lights are connected on a separate circuit ; but a single return wire answers for all.

Bare copper wire, of No. 8 gauge, is employed, and it is carried on posts from the engine-house on the west over the roof of the Suburban Station. The roof of the terminus is then entered by means of flexible insulated leads, and bare wire supported from the wall by wheel insulators is then used to convey the current to the lamps. The six lamps above each platform are fed by two separate circuits, and these interlace or cross each other so that the alternate lamps are supplied from the same circuit. With this arrangement, if any accident happens to one of the two circuits, only the alternate lamps on one side of the station will be extinguished, leaving still three lighted lamps on that side to carry on the traffic as already mentioned.

The power of each light inside the station is about 4,000 candles, but the height at which they are placed produces a very uniform and pleasing light. Three lanterns are sufficient to light each platform for all ordinary purposes, and when the whole six are turned on during the starting of a train the effect is very fine. The two lights placed on the outside are each of 6,000 candle power. They are supported from the building on simple davits and cast-iron brackets, and as they are elevated 70 feet above the ground they are enclosed in clear lanterns, for ground glass is not required to tone down their brilliance. Carré's carbons are used in the lamps, and each pair lasts about eight hours. Of course in the double-arc lantern the lighting period can be extended to sixteen hours, by diverting the current through each lamp in succession. The outside lanterns at King's Cross are of this double pattern to save trouble in supplying fresh carbons.

These twelve internal lights supersede twenty of Sugg's patent argand burners of 100 candle power on the departure platform and sixty gas jets of the ordinary 15 candle power on the arrival platform. But the light from six of the Crompton lights is quite as good as that which was formerly obtained from these gas burners. The twelve lights, therefore, give a much superior illumination, and by the terms of contract with Mr. Crompton the cost is no greater than for gas. The working expense at King's Cross is about 4d. per hour per lamp, including coal, carbons, oil, waste, petty repairs, and attendance. To this must be added the interest on the prime cost of the machines and installation; but as the Bürgin machine is comparatively inexpensive the Crompton-Bürgin light has an advantage in this respect. A Bürgin machine giving eight lights costs about £400.

With regard to the efficiency of the system we may observe that it is highest when the resistance in the external circuit is about double the internal resistance of the machine, a law which appears to hold for dynamo-electric machines in general.

Another, and perhaps one of the most important applications of electricity, is that for lighthouse illumination; and to which we have frequently drawn attention in the preceding pages. In October, 1881, some very interesting experiments were made in public, at the glass works of Messrs. Chance Brothers and Company, Smethwick, near Birmingham, with a new lamp which they had just constructed to crown the summit of the South Head Lighthouse, Macquarae Harbour, Sydney, New South Wales. It is called "a first order dioptric revolving light with the electrical arc." The lamp has a special arrangement of prisms for securing vertical divergence of the beam. It is over six feet in diameter, the height is about 9 feet, and it is the first time such dimensions have been applied to illumination by the electric arc. The lamp, or regulator, has a power of about 12,000 candles in the focus of light, and the merging beam has a luminous intensity exceeding 12,000,000 candles. The light will give flashes around half the horizon at intervals of a minute, and will make a complete revolution every 16 minutes; in average the light will be visible a distance of 40 or 50 miles. The lamp was designed for Messrs. Chance by Dr. Hopkinson, F.R.S., and is constructed for the Government of New South Wales. It will be the largest and most powerful light in the world. The experiments were thoroughly successful, the light being so intense that it could hardly be endured with the naked eye within a limited range.

We leave with regret so interesting a subject, and pass on to consider the more sober aspects of the electric light in respect to its power and cost.

Photometric Value of the Electric Light.

If our readers will refer to the article on Artificial Illumination in Vol. I., especially that portion which relates to gas, they will find a description of various apparatus that have been invented for the purpose of measuring the candle value of ordinary gas. It will be there seen that the comparison is made by employing a sperm candle burning at a definite rate in respect to time, and according to the power of the gas flame being tested, it is called 12, 16, etc., candle power; that is, it is giving as much light as 12 or 16 candles would do, of the kind above described, and of course burning together. As is well known, the methods of photometric measurement in use at the present time are very imperfect, even for lights of low intensity, and for the correct valuation of the electric arc they are proportionally more inexact. As early as 1825 it was pointed out by a Bohemian physicist, who has been dead for several years, that the sensibility of the retina varies according to the colour of the light, and that the ratio of intensity of two lights of different colours varies, for the same observer, with the distance of the screen of the standard lamp. We are indebted to *Engineering* for the following remarks in reference to the photometric value of the electric light.

In France the standard lamp employed is the Carcel, burning 42 grammes (648 grains) of olive oil per hour, with a given height of flame, a fixed diameter of wick, within a chimney as clear as practicable, and with several other conditions, which can be only approximately fulfilled. The number and nature of these conditions imply

beforehand the impossibility of obtaining a perfect lamp, and in practice it is found that the variations in the same lamp, and within a very short space of time, are as much sometimes as 5 per cent. The variations with the standard candle used in this country are much higher, owing to the greater mobility of the flame. The light given by both these standards is yellow, while that of the arc is white, and this striking difference renders exact comparison impossible, even with the interposition of a red or green glass screen. Moreover, the variations of intensity in the electric light, which are generally strongly marked, introduce another element of difficulty into the problem.

In attempting then to obtain photometric measurements, at least three grave difficulties present themselves, the differences in colour between the arc and the standard lamp, the variations in intensity, and the unknown error due to the observer. These causes of themselves are amply sufficient to vitiate the result obtained, and to account for the exaggerated statements as to the powers of different electric lights, statements which sometimes exceed the photometric value, even at the phases of maximum intensity.

The measure of this luminous intensity is a subject which has been earnestly discussed, and many suggestions have been made on the subject. By some the unit recommended is the light produced by the incandescence of a platinum wire brought to a red or white heat with a current of known intensity. Others suggested the magnesium light, others again the Drummond light, while the existing Carcel standard did not lack champions. It was even proposed, without due consideration of the practical difficulties inseparable from such a choice, to take as a standard the light emitted by the surface of platinum or silver, one centimetre square, brought to the temperature of fusion. The Congress at Paris, in 1881, arrived at no conclusion, but the result of their deliberations will doubtless be the forming of an international committee on the subject.

So far as it has been possible to obtain actual values, the intensity of the Jablochkoff candle has been ascertained, as well by the prolonged and careful investigation carried on by the Societé Générale d'Electricité, as by the photometric measurements made by the Metropolitan Board of Works on the lights on the Thames Embankment. In Paris the Municipal Council employed one of its engineers to make the most careful measurements possible, with the object of fixing the hourly value of the light in their budget, the luminous intensity of gas being taken as a basis. For its part, the Societé entrusted its consulting engineer, M. Joubert, with the work of making the fullest and approximately accurate measurements, and the results obtained, affected as they are by the inevitable imperfection of instruments and observation, give the luminous values of the Jablochkoff candles, and the power required to produce them, very closely. What follows summarises as briefly as possible M. Joubert's investigation.

1. *Comparison, made with the Foucault Photometer, of the Jablochkoff Electric Light with a Carcel Burner.* (1 *Carcel*=9.4 *Standard Candles.*)

A Jablochkoff candle burning with naked flame distributes unequal quantities of light in different directions; it is evident that the maximum corresponds to the front of the candle, and the minimum to the side view. In the latter case one of the carbons is completely masked by the other; nevertheless the light emitted sideways is, in consequence of the arc, more than half of that emitted at the front. Various experiments made show that the proportion is 0.57.

It would be a serious mistake to take as the average quantity of light given off by the candle the mean of these extreme values as $\frac{1+0\cdot57}{2}=0\cdot78$ of the maximum intensity. In fact, the curve representing the intensities such as experiment shows them to be, is not an ellipse of which the axes would have the relative dimensions 1 and 0.57; but a curve in the form of 8, diminishing very rapidly in the neighbourhood of the small axis, and of which the surface is about 0.90 of that of a circle with a radius of 1; in other words, the mean intensity is 0·90 of the maximum intensity.

If the candle is covered with a globe, and more particularly with an ordinary opal globe, the distribution changes completely, and approximates very nearly to uniformity. This may, indeed, be perceived with the naked eye; the globe, from whichever side it is viewed, appears as a disc uniformly illuminated. Nevertheless, there are differences depending on the situation of the candle in the holder and its height. Experience proves that the average is accurately realised by enclosing in a globe 4 candles, 2 with full front, and 2 sideways, each in a different phase of combustion. It is thus that the following results have been obtained: 4 candles, 2 with full front, and 2 sideways:—

Naked light: 37.5 carcel burners (mean for 1 candle)

Intensity of the candle seen from the front		45	deduced by
Mean intensity...		41	calculation.
Ordinary opal globe ...	22.5	0.575	mean intensity.
Clear	27.5	0.670	,,
	27.5	0.670	,,
	30.8	0.750	,,

2. *Experiments made with the Shadow Photometer, the Comparison being with a Burner consuming* 49.44 *cubic feet.*

The experiments made with the Foucault photometer give the intensity of the light emitted in a horizontal direction. The shadow photometer gives the measure of the illumination of the ground on which fall only the rays given out obliquely by the luminous flame. There are two different points of view in connection with this. If the rays obliquely given out light up the ground, those emitted in a horizontal direction illuminate the passers-by, the carriages, the names of the streets, the shop signs, and the numbers of the houses. All lamps give out

fewer rays downwards than horizontally; only, perhaps, the batswing burner, when it is perfect, escapes this law.

For the electric light with an opal globe, experiment gives 0.75 for an angle of 45 deg., or a diminution of 0.25. For a lamp consuming 49.44 cubic feet, the loss for this angle would be about 0.50. This is proved by experiment, from which it was found that the electric light is equal to 3.07 burners of 49.44 cubic feet; when the inclination was not more than 32 deg. for the latter, a part of the luminous ring was hidden by the crystal globe.

An exhaustive series of experiments showed that the electric light, with the ordinary opal globe, is equal to a little more than two burners consuming 49.44 cubic feet each.

In other experiments the two lights were furnished with blackened cowls which prevented any light reflected from a point in the room from falling on the photometer.

3. *Comparison of the Electric Light with a Burner consuming* 49.44 *cubic feet in the Public Street.*

The experiments made in the Place de l'Opéra, lead to the following results, the electric candle being covered with an ordinary opal globe of 19.69 in. diameter:

Compared with a burner consuming 49.44 cubic feet it is equal to 2.40 of these burners.

Compared with a burner consuming 4.944 cubic feet is equal to 17.17 of these burners.

Two results which are absolutely at variance.

The question is whether a lamp burning 49.44 cubic feet is only equal to seven ordinary burners consuming each 4.944 cubic feet, or whether some source of error crept in during one of the two experiments.

It does not appear admissible that a lamp consuming 49.44 cubic feet is equal to fourteen burners; but it is certainly equal to more than ten. This would give, in the one case, twenty-four burners, and in the other 17.17 burners for the value of the electric light, that is to say, two figures evidently incompatible.

There is, therefore, somewhere a source of error, not apparent in the first experiment. At the distance of 28-16 inch, where the photometer was placed, and which corresponded for a burner consuming 49.44 cubic feet to an inclination with the horizontal of 18 deg. only, no part of the luminous ring was hidden by the crystal globes, nor by the supports of the lamp, the reflector was in the best condition for taking effect. Besides this, the number found approaches nearly, although it is a little larger, to the mean of those obtained at the works of the Société Générale under conditions nearly similar. This experiment must hence be regarded as beyond suspicion, and it must be admitted as an established fact that the electric light is equal to from 2 to 2.4 burners consuming 49.44 cubic feet of the pattern of those of the Rue du Quatre Septembre.

The error must hence be found in the second experiment. It is always inconvenient to adopt a unit too small in comparison with the quantity to be measured. This inconvenience does not amount to much with the Foucault photometer, because it is always possible to place the two lights in such a way that the feebler still shows sufficient intensity on the card. If a Carcel burner or a gas burner consuming 5 cubic feet is in question, it is well that this distance should not be greater than 5 feet or 6 feet 6 inches. After that the intensities become too feeble, and the eye loses a large portion of its sensibility; now, in the actual experiment, the intensity was that of a gas burner placed at a distance of more than 23 feet.

In spite of this it appears tolerably certain that the distance measured, 24 feet 7.28 inches, was not in error more than 7.87 inches one way or the other, and that it may be admitted that the true distance was comprised between

$$24 \text{ ft. } 7.28 \text{ in.} \pm 7.87 \text{ in.} \begin{cases} 23 \text{ ft. } 11.41 \text{ in.} \\ 25 \text{ ft. } 3.15 \text{ in.} \end{cases}$$

But the first distance gives for the maximum value of the electric light

60 ft. 0.48 in. = (54 ft. 9.48 in. + 5 ft. 2.99 in.),

and the second for the minimum value

49 ft. 6.49 in. = (54 ft. 9.48 in. + 5 ft. 2.99 in.)

The variation from the amount which ought to have been obtained is inconsiderable, and the reason suggested insufficient to explain the disagreement.

But the fault of the sensibility of the eye is the least of the inconveniences which are met with in employing very feeble intensities. The least external light assumes an influence relatively very great, and modifies the result considerably.

If the arrangement of the two luminous flames is considered and compared, it will be seen that the electric burner was isolated, and far from any illuminated surface, while the burner consuming 4·944 cubic feet was placed at a distance of about 9 feet 10·11 inches from a wall, of a dark colour it is true, but which received the light of the gas burner and that of the electric light, and reflected on the photometer a certain portion of these lights. It was a mistake that the portion of the wall capable of acting on the photometer was not covered with a black curtain, as had been done in the case of the burner consuming 49·44 cubic feet.

The results given in the foregoing summary refer to candles with carbons of 4 mm. (.16 in.) diameter. The conditions under which the light was produced were very variable for several reasons, namely, the number of candles burning on the same circuit, the speed at which the dynamo-machine was driven, and the length of the circuit. These conditions may be harmonised by reducing the length of the incandescent cone to 15 mm. (.55 in.), a greater length indicating an excess of quantity, and a less height an excess of tension. With candles of different types the luminous power obtained was variable. Thus in front of the Grand Café, the bougies employed have carbons .12 inches in diameter, and give an intensity of about 25 Carcels. The lighting of the Havre Docks, on the other hand, is effected with candles having carbons .24 inch in diameter, and giving about 65 Carcels intensity. Speak-

ing generally, it may be said that it is possible to obtain exactly a given intensity by modifying the type of the candle, the intensity of the current, and the mode of adjusting the circuit.

Under ordinary conditions in using the Jablochkoff candles, which are almost necessarily placed at no great height from the ground, a large proportion of the light is intercepted by the globe or screen placed over it. The Société Générale d'Electricité, with the assistance of glass manufacturers, has conducted numerous experiments with different classes of interceptors—"diffusion" globes, ground, crackled, opaline globes, etc. It has also been attempted, in accordance with the wishes of certain customers, to give a yellow hue to the light. These attempts have not been successful, since the ground or opaline globes are not quite uniform in thickness, and the tint given to them has consequently been more or less unequal; moreover, colouring the light in this way is accompanied by a very considerable absorption. Scarcely more satisfactory were the experiments of placing a tinted chimney over the light within the globe. The colour of the light is, after all, to a great extent, a matter of taste created by custom. Instinct leads us to prefer the warm yellow light of gas or oil to the cold pure illumination of the arc, despite the fact that the latter enables us to see the most delicate shades of colour in all their natural hues. By the time the science of electric lighting is sufficiently advanced to drive gas from our streets, offices, and homes, the questions of diffusion, steadiness, control, and with these and many other points, the question of colour, will have been satisfactorily solved, as, indeed, it has been in those important types of lamps shown by Edison, Swan, and others, at the Exhibition.

The various systems of screening the Jablochkoff light are all necessarily attended with considerable loss, varying with the medium employed and the arrangement adopted. Among the various modes, we may refer, as a curiosity, to one in use at the Magazins du Louvre for many months, and which consists in covering the transparent globes with a saline solution, that after evaporation leaves a slight film on the surface of the glass. In another method "glass wool" is used, and more practical than these is the system devised by M. Paris, a glass manufacturer of Bourget, which consists in casting transparent glass in grooved globular moulds. These grooves are very numerous and close together; they hide the luminous point of the candle, and cut off very little light.

The problem of ascertaining the motive power necessary to produce the various systems of electric light, is environed by the same difficulties that attend its measurement, and, indeed, wholly depends on the measurement of the light. The power absorbed of course may be easily known, but it affords no idea of the value of any given systems to learn that one arc absorbs three powers, and another only one. As a matter of fact, however, nothing has been more difficult hitherto than to learn precisely the power required to produce any arc light.

As regards the consumption of power by the Jablochkoff candles, it averages at present about one-horse power for from 40 to 45 Carcels.

Cost of the Electric Light, compared with that of Gas.

In the preceding pages we have fully described what the electric light can do as an illuminative, and in the last section we have discussed the means that have been taken to ascertain its photometric value. A still more important question is that of its cost. It is so difficult to obtain actual details of the cost of the electric light, and of its comparison with gas, that the following information will be read with considerable interest. It is extracted from the report issued in October, 1881, of Lieut.-Colonel Festing, R.N., the Assistant Director of the South Kensington Museum, who is specially entrusted with the charge of the building.

"The total consumption of gas in the Museum schools, etc., at South Kensington, has been 26,590,200 feet, costing £4,431 14*s.*

"The consumption at South Kensington shows a diminution, as compared with the previous year, of 2,230,100 feet, and of £612 7*s.* The diminution is accounted for by the fact that since March, 1880, one-half, and since June the whole of the Lord President's Court has been lighted by the electric light. The weather on the whole, too, has been lighter than in the previous year. The price of gas was reduced from 3*s.* 6*d.* to 3*s.* 4*d.* on the first of January.

"Sir Frederick Leighton, P.R.A., having expressed his fears that the mural painting recently executed by him in the Lord President's Court might be injured by the gas, it was decided to try to light this court by the electric light. The 'Brush' system, which had quite lately been introduced into this country from America, appeared in many respects to be that best suited for the purpose, and a dynamo-electric machine and eight lamps on this system were therefore purchased to light up the eastern half of the court. The machine was driven by the gas-engine, and the result was so far satisfactory that it was determined to extend the lighting to the other half of the court; but as the gas-engine is not sufficiently powerful to work the sixteen lamps, a semi-portable steam-engine was purchased for the purpose from Messrs. Ransome, Sims, and Head, of Ipswich, and placed in a temporary shed between the office building and the Patent Office Museum, and towards the end of June the lighting of the whole court was commenced, and has been uninterruptedly continued ever since.

"The light is, on the whole, satisfactory, though it is not so steady as could be wished, and a slight increase in quantity of light would perhaps be desirable. The present machine, however, is incapable of working more lamps. These latter are suspended from the roof, and are raised and lowered by means of cords, which have a prejudicial effect on the appearance of the court. I am, however, having arrangements

made to do away with these cords, which will be applied after the present gas fittings have been removed. This apparently may now be done with safety, as the electric lights have worked without any accident for so long.

"Between the 22nd of June and the 31st of December the 16 lamps were at work on 87 nights for a total of 359 hours. The total consumption of coal (Merthyr), including what was used in getting up steam, was 13 tons, or 81 lbs. per hour's work. The engine indicates between 20 and 21 horse power, but is capable of working up to double this power; it will therefore be able to drive a second machine as well, and no doubt we shall get a comparative diminution in the consumption of coal, which is even now small for an engine of this class. The automatic expansion gear of Messrs. Ransome and Co. attached to the engine acts in a highly satisfactory manner, the speed of the machine, as shown by the tachometer attached to it, being perfectly regular.

"The only actual addition to the wages on account of the electric light has been to those of the stoker, which amount to 25s. a week. The engine fitter who looks after the engine has replaced a gasfitter.

"The working cost for the period referred to has been as follows :—

	£	s.	d.		s.	d.	
Carbons ...	18	9	0	or	1	0	per hour of lighting
Oil, cotton waste, etc.	4	11	6	,,	0	3	,, ,,
Coal ...	11	14	0	,,	0	8	,, ,,
	34	14	6	,,	1	11	,, ,,
Wages ...	34	7	6	,,	1	11	,, ,,
Total	69	2	0	,,	3	10	,, ,,

"The consumption of gas, which used to be at the rate of 16s. an hour, would for the same period have been £287 4s. The saving on working expenses has therefore been £218 2s., or at the rate of about £420 per annum.

"The outlay was as follows :—

	£
Cost of dynamo-electric machine ...	400
,, lamps and fixing; conducting wires, etc.	384
Cost of steam-engine and fixing; shafting, belting, etc.	420
	1,204

"As, however, the steam-engine is capable of driving two such machines, the cost of the machinery and apparatus for lighting the court may be said in round figures to have been £1,000, on which outlay the saving on working expenses, as compared with gas, represents 42 per cent. per annum. The machinery at present shows no sign of deterioration from wear or tear, nor do I see any reason to expect any great expense on this score. I hope that with increased experience we may obtain greater steadiness in the light, and perhaps even some slight diminution of working expenses.

"I propose next to try similar lamps in some of the picture galleries and in the Art Schools, in which latter there are great complaints of the bad state of the atmosphere in the evenings caused by the gas. I hope also before long to be able to try some of the incandescence lamps of Swan or Lane Fox, which promise to be very suitable for the reading-room, and perhaps even for the offices."

Electricity and Horticulture.

One of the most interesting applications of the Electric Light that has yet been made, and perhaps the most astonishing, is that of applying it to cause the growth of plants entirely independent of sunlight. This has been effected by Dr. C. W. Siemens. The following is an abstract of a paper read by him before Section A of the British Association, entitled, *On some applications of Electric Energy to Horticultural and Agricultural Purposes* in 1881 :—

"On the 1st of March, 1880, I communicated to the Royal Society a paper 'On the Influence of Electric Light upon Vegetation, etc.,' in which I arrived at the conclusion that electric light was capable of producing upon plants effects comparable to those of solar radiation; that chlorophyl was produced by it, and that bloom and fruit, rich in aroma and colour, could be developed by its aid. My experience also went to prove that plants do not, as a rule, require a period of rest during the 24 hours of the day, but make increased and vigorous progress if subjected (in winter time) to solar light during the day, and to electric light during the night.

"During the whole of last winter I continued my experiments on an enlarged scale, and it is my present purpose to give a short account of these experiments, and of some further applications of electric energy to farming operations (including the pumping of water, the sawing of timber, and chaff and root cutting) at various distances not exceeding half a mile from the source of power-giving useful employment during the day time to the power-producing machinery, and thus reducing indirectly the cost of the light during the night time.

"The arrangement consists of a high-pressure steam-engine of six-horse power nominal, supplied by Messrs. Tangye Brothers, which gives motion to two dynamo machines (Siemens D) connected separately to two electric lamps, each capable of emitting a light of about 4,000 candle power. One of these lamps was placed inside a glass house of 2,318 cubic feet capacity, and the other was suspended at a height of 12 feet to 14 feet over some sunk greenhouses. The waste steam of the engine was condensed in a heater, whence the greenhouses take their circulating supply of hot water, thus saving the fuel that would otherwise be required to heat the stoves.

"The experiments were commenced on the 23rd of October, 1880, and were continued till the 7th of May, 1881. The general plan of operation consisted in lighting the electric lights at first at 6 o'clock, and during the short days at 5 o'clock every evening except Sunday, continuing their action until dawn.

"The outside light was protected by a clear glass lantern, whilst the light inside the house was left naked in the earlier experiments, one of my objects being to ascertain the relative effect of the light under these two conditions. The inside light was placed at one side over the entrance into the house, in front of a metallic reflector, to save the rays that would otherwise be lost to the plants inside the house.

"The house was planted in the first place with peas, French beans, wheat, barley, and oats, as well as with cauliflowers, strawberries, raspberries, peaches, tomatoes, vines, and a variety of flowering plants, including roses, rhododendrons, and azaleas. All these plants being of a comparatively hardy character, the temperature in this house was maintained as nearly as possible at 60 deg. Fahr.

"The early effects observed were anything but satisfactory. While under the influence of the light suspended in the open air over the sunk houses, the beneficial effects due to the electric light observed during the previous winter repeated themselves, the plants in the house with the naked electric light soon manifested a withered appearance. Was this result the effect of the naked light, or was it the effect of the chemical products, nitrogenous compounds and carbonic acid, which are produced in the electric arc?

"Proceeding on the first named assumption, and with a view of softening the ray of the electric arc, small jets of steam were introduced into the house through tubes, drawing in atmospheric air with the steam and producing the effects of clouds interposing themselves in an irregular fashion between the light and the plants. This treatment was decidedly beneficial to the plants, although care had to be taken not to increase the amount of moisture thus introduced beyond certain limits. As regards the chemical products, carbonic acid and nitrogenous compounds, it was thought that these would prove rather beneficial than otherwise in furnishing the very ingredients upon which plant life depends, and further that the constant supply of pure carbonic acid resulting from the gradual combution of the carbon electrodes, might render a diminution in the supply of fresh air possible, and thus lead to economy of fuel. The plants did not, however, take kindly to these innovations in their mode of life, and it was found necessary to put a lantern of clear glass round the light, for the double purpose of discharging the chemical products of the arc, and of interposing an effectual screen between the arc and the plants under its influence.

"The effect of interposing a mere thin sheet of clear glass between the plants and the source of electric light was most striking. On placing such a sheet of clear glass so as to intercept the rays of the electric light from a portion only of a plant, for instance a tomato plant, it was observed that in the course of a single night the line of demarcation was most distinctly shown upon the leaves. The portion of the plant under the direct influence of the naked electric light, though at a distance from it of nine feet to ten feet, was distinctly shrivelled, whereas that portion under cover of the clear glass continued to show a healthy appearance, and this line of demarcation was distinctly visible on individual leaves. Not only the leaves but the young stems of the plants soon showed signs of destruction when exposed to the naked electric light, and these destructive influences were perceptible, though in a less marked degree, at a distance of twenty feet from the source of light.

"A question here presents itself that can hardly fail to excite the interest of the physiological botanist. The clear glass does not apparently intercept any of the luminous rays, which cannot therefore be the cause of the destructive action. Professor Stokes has shown, however, in 1853, that the electric arc is particularly rich in highly refrangible invisible rays, and that these are largely absorbed in their passage through clear glass; it therefore appears reasonable to suppose that it is these highly refrangible rays beyond the visible spectrum that work destruction on vegetable cells, thus contrasting with the luminous rays of less refrangibility, which, on the contrary, stimulate their organic action.

"Being desirous to follow up this inquiry a little further, I sowed a portion of the ground in the experimental conservatory with mustard and other quick-growing seeds, and divided the field into equal radial portions by means of a framework, excluding diffused light, but admitting light at equal distances from the electric arc. The first section was under the action of the naked light, the second was covered with a pane of clear glass, the third with yellow glass, the fourth with red, and the fifth with blue glass. The relative progress of the plants was noted from day to day, and the differences of effect upon the development of the plants were sufficiently striking to justify the following conclusion, viz., under clear glass the largest amount of and most vigorous growth was induced; the yellow glass came next in order, but the plants, though nearly equal in size, were greatly inferior in colour and thickness of stem to those under the clear glass; the red glass gives rise to lanky growth and yellowish leaf; while the blue glass produces still more lanky growth and sickly leaf. The uncovered compartment showed a stunted growth, with a very dark and partly shrivelled leaf. It should be observed that the electric light was kept on from 5 P.M. to 6 A.M. every night except Sundays during the experiment, which took place in January, 1881, but that diffused daylight was not excluded during the intervals, also that circulation of air through the dividing framework was provided for.

"These results are confirmatory of those obtained by Dr. J. W. Draper in his valuable researches on plants in the solar spectrum in 1843, which led him to the conclusion in opposition to the then prevailing opinion that the yellow ray and not the violet ray was most efficacious in promoting the decomposition of carbonic acid in the vegetable cell.

"Having in consequence of these preliminary inquiries determined to surround the electric

arc with a clear glass lantern, more satisfactory results were soon observable. Thus, peas which had been sown at the end of October produced a harvest of ripe fruit on the 16th of February, under the influence, with the exception of Sunday nights, of continuous light. Raspberry stalks put into the house on the 16th of December produced ripe fruit on the 1st of March, and strawberry plants put in about the same time produced ripe fruit of excellent flavour and colour on the 14th of February. Vines which broke on the 26th of December produced ripe grapes of stronger flavour than usual on the 10th of March. Wheat, barley, and oats shot up with extraordinary rapidity under the influence of continuous light, but did not arrive at maturity, their growth having been too rapid for their strength, caused them to fall to the ground after having attained the height of about 12 inches.

"Seeds of wheat, barley, and oats planted in the open air and grown under the influence of the external electric light produced, however, more satisfactory results; having been sown in rows on the 6th of January, they germinated with difficulty on account of frost and snow on the ground, but developed rapidly when milder weather set in, and showed ripe grain by the end of June, having been aided in their growth by the electric light until the beginning of May.

"Doubts have been expressed by some botanists whether plants grown and brought to maturity under the influence of continuous light would produce fruit capable of reproduction; and in order to test this question, the peas gathered on the 16th of February from the plants which had been grown under almost continuous light action, were replanted on the 18th of February. They vegetated in a few days, showing every appearance of healthy growth.

"Further evidence on the same question will be obtained by Dr. Gilbert, F.R.S., who has undertaken to experiment upon the wheat, barley, and oats grown as above stated, but still more evidence will probably be required before all doubt on the subject can be allayed.

"I am aware that the great weight of the opinion of Mr. Darwin goes in favour of the view that many plants, if not all of them, require diurnal rest for their normal development, and it is with great diffidence, and without wishing to generalise, that I feel bound to state as the result of all my experiments, extending now over two winters, that although periodic darkness evidently favours growth in the sense of elongating the stalks of plants, the continuous stimulus of light appears favourable for healthy development at a greatly accelerated pace, through all the stages of the annual life of the plant, from the early leaf to the ripened fruit. The latter is superior in size, in aroma, and in colour to that produced by alternating light, and the resulting seeds are not at any rate devoid of regerminating power.

"Further experiments are necessary, I am aware, before it would be safe to generalise, nor does the question of diurnal rest in any way bear upon that of annual or winter rest, which probably most plants, that are not so-called annuals, do require.

"The beneficial influence of the electric light has been very manifest upon a banana palm, which at two periods of its existence, viz., during its early growth and at the time of the fruit development, was placed (in February and March of 1880 and 1881) under the night action of one of the electric lights, set behind glass at a distance not exceeding two yards from the plant; the result was a bunch of fruit weighing 75 lbs., each banana being of unusual size, and pronounced by competent judges to be unsurpassed in flavour. Melons also remarkable for size and aromatic flavour have been produced under the influence of continuous light in the early spring of 1880 and 1881, and I am confident that still better results may be realised where the best conditions of temperature and of proximity to the electric light have been thoroughly investigated.

"My object hitherto has rather been to ascertain the general conditions necessary to promote growth by the aid of electric light, than to the production of quantitative results, but I am disposed to think that the time is not far distant when the electric light will be found a valuable adjunct to the means at the disposal of the horticulturist in making him really independent of climate and season, and furnishing him with a power of producing new varieties.

"Before electro-horticulture can be entertained as a practical process it would be necessary, however, to prove its cost, and my experiments of last winter have been in part directed towards that object. Where water power is available the electric light can be produced at an extremely moderate cost, comprising carbon electrodes, wear and tear of and interest upon apparatus and machinery employed, which experience elsewhere has already shown to amount to 6*d.* per hour for a light of 5,000 candles. The personal current attention requisite in that case consists simply in placing the carbon electrodes every six or eight hours, which can be done without appreciable expense by the under gardener in charge of the fires of the greenhouses.

"In my case no natural source of power was available, and a steam-engine had to be resorted to. The engine of six nominal horse power, which I employed to work the two electric lights of 5,000 candles power each, consumes 56 lbs. of coal per hour (the engine being of the ordinary high pressure type), which taken at 20*s.* a ton would amount to 6*d.*, or to 3*d.* per light of 5,000 candles. But against this expenditure has to be placed the saving of fuel effected in suppressing the stoves for heating the greenhouses, the amount of which I have not been able to ascertain accurately, but it may safely be taken at two-thirds of the cost of coal for the engine, thus reducing the cost of the fuel per light to 1*d.* per hour; the total cost per light of 5,000 candles will thus amount to 6*d.* + 1*d.* = 7*d.* per hour.

"This calculation would hold good if the electric light and engine power were required during, say, twelve hours per diem; but inasmuch as the light is not required during the

daytime, and the firing of the boiler has nevertheless to be kept up in order to supply heat to the greenhouses, it appears that during the daytime an amount of motive power is lost equal to that employed during the night.

"In order to utilise this power I have devised means of working the dynamo-machine also during the daytime, and of transmitting the electric energy thus produced by means of wires to different points of the farm where such operations as chaff-cutting, swede-slicing, timber-sawing, and water-pumping have to be performed.

"These objects are accomplished by means of small dynamo-machines placed at the points where power is required for these various purposes, and which are in metallic connection with the current generating dynamo-machine near the engine. The connecting wires employed consist each of a naked strand of copper wire supported on wooden poles or on trees, without the use of insulators, whilst the return circuit is effected through the park railing or wire fencing of the place, which is connected with both transmitting and working machines by means of short pieces of connecting wire. In order to insure the metallic continuity of the wire fencing, care has to be taken, wherever there are gates, to solder a piece of wire buried below the gate to the wire fencing on either side.

"As regards pumping the water, a three horse power steam-engine was originally used, working two force pumps of $3\frac{1}{2}$ inches diameter making 36 double strokes per minute. The same pumps are still employed, being now worked by a dynamo-machine weighing 4 cwt. When the cisterns at the house, the gardens, and the farm require filling, the pumps are started by simply turning the commutator at the engine station, and in like manner the mechanical operations of the farm already referred to are accomplished by one and the same prime mover.

"It would be difficult in this instance to state accurately the percentage of power actually received at the distant station, but in trying the same machines under similar circumstances of resistance with the aid of dynamo-meters as much as sixty per cent. has been realised."

Storage of Electricity.

At first sight it would appear somewhat ridiculous if we stated that it lies within our power to keep a stock of electricity in hand ready for any purpose, but if we view the subject carefully, the difficulties practically disappear, especially if we use the aid of analogy. A lump of ordinary coal presents no appearance externally of being a storehouse of light and heat. But practically there is no fact in our lives that is so familiar to us. If we take the proper steps, that is, ignite the coal or any other combustible substance, the light and heat *stored up* in the coal is set free. Hence our fires, our gas-light, etc., etc., etc. Similarly, or perhaps more correctly, analogically, if we rub a piece of glass, resin, etc., we set free electricity; if we use a voltaic battery, we perform the same thing, and as we have already pointed out in the preceding pages, similar results may be obtained by electro-magnetism and magneto-electricity.

If our readers carefully peruse the article on Electro-Metallurgy in this work, they will find that by means of the voltaic battery, copper and most other metals may be easily deposited, in any quantity, by means of a voltaic cell, or cells acting on plates immersed in a suitable solution. This has been fully described in detail, in the article on Electro-Metallurgy. It will there be seen that the current passing from the negative plate of the battery reaches and enters the decomposing cell in which a plate is immersed in a solution of the same metal, connected with the negative plate of the battery by a wire. This plate gradually undergoes solution, and by the nascent hydrogen, is precipitated in the metallic form on the plate, model, or other object opposite to it in the cell, these latter gaining as much metal as is dissolved off the positive plate opposed to them, the current then passing to the battery.

But in the various forms of the batteries or accumulators, used for storing electricity, a somewhat different plan is adopted, although the principle is the same. A plate of lead is bent so that half of it is in one trough or cell, and the other half in an adjacent one. Such a trough, represented by Fig. 136 as used for Wollaston's battery, will answer for the purpose of experiment. In this case 10 cells are represented, and the plates of lead are arranged so that the surface of one plate is in cell No. 1, while the surface of its other end is bent into No. 2, and so on throughout the series; terminal wires being soldered to the last plates of each end, and the cells being filled with an acid solution.

Now it is obvious that if the two terminal wires be brought together no action will take place because only one metal and one fluid is employed. But if the two wires be connected with a voltaic battery, chemical action will at once commence. One plate will part with its lead, which will produce a surface of peroxide of lead on the opposite one. The action of the battery is continued for some time, and then the lead trough wires may be disconnected with it. If now the wires of the lead trough be brought together and separated they will give a spark, and if the accumulator, as this arrangement is called, be large enough, an electric light may be obtained by carbons in the usual way, wires may be melted, and other luminous and calorific effects of a voltaic battery be obtained.

But gradually the power of producing these effects passes away. The peroxide of lead is gradually reduced into the metallic form, and when this operation is completed the accumulated force is all used up. It is evident, therefore, that we can store up electricity to a certain extent dependent on the size of the accumulator and the exciting power of the battery or dynamo-electric machine used for the purpose. It is on this principle that the accumulators of Planté, Faure, and De Meritens are constructed.

In reference to the method of storing elec-

tricity, and the plans that have been adopted, we quote the following remarks made by Sir W. Thomson, at the meeting of the British Association in 1881, in a paper entitled, *On Some Uses of Faure's Accumulator in Connection with Lighting by Electricity* :—

"The first and most obvious use of Faure's accumulator was stated by the author to be the production of electric energy at the most convenient time, and to keep it in store until it could be most conveniently used ; but its largest use in electric lighting would be to allow steam or other motive power and the dynamo to work economically all day, or throughout the twenty-four hours, where the circumstances were such as to render that economical, and then storing up the energy so that it might be drawn upon when the light was required. There was also a very valuable use of the accumulator in its application as an adjunct to the dynamo, in order to fulfil the first condition of giving greater regularity to the light-giving current and storing up an irregular surplus in such a manner that the stoppage of the engine would not stop the light, but only reduce it slightly, and so also that there would always be a good residue of two or three hours' supply of full lighting power after the driving machine was stopped, or a supply of light for eight or ten hours for a diminished number of lamps. It was obvious that great economy and important practical results were to be obtained by the use of such a system, provided that the expense of the storing material and the magnitude and bulkiness of the apparatus that it involved were not prohibitory —were not such as run away with whatever gain there might be in the principle. The subject, Sir William remarked, was altogether in its infancy, and we must wait for fuller information, both as to its practical and its economic sides. So far as estimating electrical quantities was concerned, we must hold our hands until along with the incandescent lamps given us there was a statement that they would continue in action giving out so many candles' power, approximately, when so many volts were applied to them, and during such and such a time. After some further remarks, Sir William proceeded to illustrate the two methods of applying the connecting dynamo machines as suited to the single circuit dynamo and as suited to the shunt dynamo. He exhibited an automatic instrument which he had designed and constructed to break and make the circuits between the Faure battery and the dynamo, so as automatically to fulfil the condition described in the paper. The same instrument also guarded the coils of the dynamo from damage, and the accumulator battery from loss by the current flowing back, if at any moment the electro-motive force of the dynamo flagged to such a degree as to be overpowered by the battery."

Electricity as a Motive Power.

If the reader refers to the article on Electro-Magnetism, he will find, at p. 411, *et seq.*, a detailed account of all the failures that have, until recently, resulted from attempts to apply electricity as a motive power. We are indebted for the following *résumé* of the present position of the question to the periodical we have already frequently quoted in the preceding pages.

It may be safely predicted that of all the practical applications of electricity, that which will receive the most powerful impulse from the 1881 Exhibition at the Palais de l'Industrie, in Paris, will be its application for motive power. During the past few years the investigations of physicists and the ingenuity of inventors have been especially directed to the industrial production and utilisation of electric currents for lighting purposes, and the success which has attended all this labour needs no comment. But with the exception of a few interesting but chiefly restricted applications, the whole field of force produced by electricity has remained untouched. The Exhibition has come at the right time to encourage research in this direction, and to show results, relatively small as they are, the practical value of which will strike every one.

Besides coal, the great source of power, but one which in a somewhat remote future will be exhausted, there exist on the surface of the globe certain natural forces of an absolute permanence, which are inexhaustible, and which possess the means of yielding energy to an enormous degree, but whether of practical utility in proportion to their amount has to be seen.

The chief of these are watercourses and waterfalls. For many centuries water power has been utilised for numerous industries, and the transmission of hydraulic power to considerable distances has also been accomplished by means of cables, as at Schaffhausen. But the direct application of water power must always be local, and hitherto has been limited to the site of the supply. Electricity, on the other hand, allows of the transmission and distribution at a distance of power produced by the fall of water, by steam-engines or by other means. As regards steam-engines, a very possible source of economy may be found in utilising the coal at the point of extraction, where its price is a minimum, and in transmitting the force produced instead of transporting the fuel. At the Exhibition of Electricity, at Paris, in 1881, were shown ranged in batteries on one side of the great nave, a series of electric machines driven by various motors which communicated to them a rapid rotation by means of belting. This movement is transformed into electricity; but the same machines, if there was furnished to them from some other source the electricity which they themselves produce by rapid revolution, would themselves revolve, and transmit to the shafts and belting connected with them a power that could be utilised. This is the interesting phenomenon known as the reversibility of magneto and dynamo-electric machines. The first time that such a system was employed was at the Vienna Exhibition of 1873, where M. H. Fontaine coupled up two Gramme machines, one of which, driven by a motor, transmitted the current produced to the second, which drove some pumping machinery.

Since that time this principle has been generalised and employed under very different practical conditions. The transmission of force by means of two dynamo-electric machines coupled together is not effected without much loss. About 50 per cent. indeed is the difference between the power applied and that delivered. But great as this waste is, it is not too extravagant to permit of application in certain cases, and sometimes to give an economy over a number of small independent steam motors, as compared with the power produced by one large central motor, less costly than a number, and consuming less fuel. And the economy is of course far greater when the source of power is natural and costs nothing. Electricity thus furnishes a means at once simple and convenient of distributing the power developed by a fall of water, over a considerable radius, by dynamo machines located at the source of power, and driven by turbines, with a system of insulated conductors, transmitting the currents to a series of distributing machines. Sir W. Thomson's proposition thus to utilise the Falls of Niagara has been too often repeated to render its mention necessary here. But it is a proposition that will doubtless before long be carried more or less fully into execution, and nothing appears more natural to conceive than the establishment of a system of conductors to transmit power, when we consider the stupendous *réseau* of wires all over the world for the transmission of telegraphic signals, and to a more limited extent of direct speech by the telephone.

Practically, however, the problem is a complicated one, and possesses some unknown elements yet to be examined. Experiments have been comparatively few, and restricted to short distances and to relatively small powers. An objection raised against the system is the necessity of employing as conductors, copper wires of a diameter increasing with distance, and it has been urged that all the mines of Lake Superior could not supply the metal necessary to make the conductors that would be required for the United States, while if copper mines have to be exhausted to economise coal, no advantage could be gained. The advocates of the system, on the other hand, maintain that a wire thirteen millimetres in diameter would suffice to transport the current to any desired distance. The truth lies between these exaggerated extremes, and will probably be arrived at before long. The question is so important, so vital possibly to the future of industry, that it cannot long remain unanswered.

The Electrical Exhibition at Paris, in 1881, contained several applications of the transmission to a distance of currents devoted to the production of energy, and these we propose to pass in review. In place of using two machines, the one productive and the other receptive of the current, connected in circuit, the receptive machine may be supplied by a battery or by an accumulator like the Planté or Faure secondary batteries. The Force et Lumière Company, which was working the Faure invention with great success, has used this system of accumulators for transporting vehicles on tramways. The special arrangements of Messrs. Siemens for working electric railways are also eminently practical and convenient. We shall for the present confine ourselves to one interesting though purely experimental installation, working at the Exhibition, namely, the electric boat of M. Trouvé.

The system adopted by M. Trouvé consists in the production of the current by means of a secondary Planté battery or a Trouvé bichromate battery, actuating a small motor devised by M. Trouvé. There is no need to describe the Planté battery, though there appears to be little accurate information as to its actual performance, but we may give a few words to the Trouvé bichromate battery, which has been recently modified by the inventor. The use of bichromate of potash was suggested for the first time in 1854 by Poggendorf, who wished to investigate, by depolarisation, the well-known chemical reaction which takes place when bichromate of potash and dilute sulphuric acid are brought together. The formula is as follows:—

$$KO\ .2\ Cr\,O^3+4\ SO^3=Cr^2O^3\ 3\ SO^3+KO\ .\ SO^3+O^3.$$

Poggendorf gave to his battery the form of a Bunsen element. A porous jar containing a cylinder of carbon and a mixture of 100 of water, 12 of bichromate of potash, and 25 of sulphuric acid, was placed in a glass vessel containing a sheet of zinc rolled into a cylinder, and sulphuric acid diluted with twelve times its weight of water. The Poggendorf battery did not give the results desired by its inventor. It developed at first a considerable electro-motive force, but contrary to expectation, polarisation took place rapidly. In 1858 M. Grenet modified the Poggendorf battery, and devised the form now known in France as the "Pile bouteille." The receiver is globular, with a very wide neck; the electrodes are composed of two pieces of retort carbon fixed to the cover of the battery, and between which passes a zinc plate that may be placed in the liquid (bichromate, water and sulphuric acid) or withdrawn, so that there may be no destruction when the battery is not in use. M. Trouvé has modified this well-known form, and has made it in a manner which permits of easily cleaning, of rapid amalgamation and replacing the zincs, and diminishes the resistance on account of the large surfaces obtained. The battery consists of two plates of hard rubber, which can be easily coupled with three other plates of the same material to form the vase. The plates support a rod on which are placed the movable contacts carrying the carbons. The tube is for blowing in air to assist in degaging the bubbles of hydrogen, and to aid the precipitation of a yellow powder that covers the carbons, and reduces the intensity of the current. Distance strips of rubber are placed above and below the carbons to prevent their contact with the zincs. Several models of this battery were exhibited by M. Trouvé at the Palais de l'Industrie. He has also introduced a further simplification, by reducing it to a simple bar, on which the electrodes are placed. The

upper faces of the carbons are thickly electroplated to increase their strength. As to the zincs, they are slotted so that they can be placed on or taken off the central bar with the greatest ease.

The Trouvé motor was explained by the inventor for the first time before the Academy of Sciences on the 28th of June, 1880. The following is a summary of M. Trouvé's remarks :—If the dynamic diagram of a Siemens coil, making a complete revolution between the magnetic poles reacting on it, is traced out, it will be seen that the work is almost *nil* during two very sensible portions of the revolution. These correspond to the time during which the cylindrical poles of the coil, having arrived at the poles of the magnet, pass before them. During these two portions of the revolution, which are each about 30 deg., the magnetic surfaces, which react one on the other, remain at the same distance; the coil is not therefore induced to revolve, and a loss of work takes place. In the Trouvé motor these idle periods are removed, and the useful effect of the apparatus is increased by modifying the coil; the polar faces, instead of being parts of a cylinder, the axis of which coincides with that of the whole system, are made spiral, so that in turning they approach gradually to the surface of the magnet, up to the moment when the rear edge passes the pole of the magnet. The action of repulsion then commences, and the dead points are practically suppressed. M. Trouvé has described in his patent several forms of his little motor. A similar arrangement was exhibited at Paris at the stand of the Electro-Dynamic Company, of Philadelphia; in this the fixed electro-magnet is formed of an iron cylinder round a part of which the wire is coiled. In one of M. Trouvé's arrangements the magnet tube is oval and the coil circular, and in another the magnet is circular and the coil is spiral.

With this device M. Trouvé has been enabled to obtain really remarkable results as compared with the weight of the apparatus. The first application was made on the 8th of April, 1881, in the Rue de Valois, near the Palais Royal, Paris. A tricycle, weighing 120 lbs., was driven by means of a motor and six Planté secondary batteries. The weight of the vehicle, including that of the rider, the batteries, and the motor, was 350 lbs. The motor, weighing 11 lbs., propelled the vehicle at the rate of $7\frac{1}{2}$ miles an hour. Shortly afterwards a second application was made to a small boat called the "Telephone," which was shown at the Exhibition at work on the central basin, from the middle of which the great lighthouse was reared.

This application is not a new one. So early as 1839 Jacobi conducted experiments on the Neva with electric propulsion. But the motor he employed was very heavy, and the acid fumes from the Bunsen batteries rendered the trial impossible. M. Trouvé has avoided both these evils by using a motor of great lightness, and a battery giving off no deleterious gases. The first of these later trials took place on the Seine, near the Pont Royal, on May 26 to 28, 1881, and on June 3, and afterwards on June 19 and 20, in the presence of a number of distinguished persons. The experiments were made under the following conditions :—The boat went up the Seine from the Pont Royal, as far as the Pont de St. Pères, and then returned to the point of departure. The speed attained was 5 feet per second, or 3·4 miles per hour against the current, and 8·5 feet a second with the stream. The screw employed had three blades. On the lake in the Bois de Boulogne the speed attained was 10 feet a second, with a four-bladed screw. The boat was 18 feet long and 4 feet wide; the weights were as follow :—

		lbs.
Weight of boat	. . . . . .	176
,, batteries	. . . . .	52.8
,, motor	. . . . . .	11
,, three passengers	. .	528
Total	. . . . . .	767·8

In reference to the applications of electricity to pumping, agricultural work, etc., some remarks of Dr. Siemens will be found at the conclusion of his interesting paper on Electricity Applied to Horticulture, at page 586, *ante*. Messrs. Siemens have succeeded in making an electrical railway, on which a carriage containing passengers have been conveyed. The electricity was supplied by one of their machines, the current being conveyed from the dynamo by means of the rails on which the carriage moved; there being inside the latter another and similar machine affording the motive power. M. Menier, of chocolate notoriety, has succeeded in employing electricity as a motive power in the field and in the barn, for ploughing, threshing, and other agricultural operations.

From the preceding remarks and illustrations it will be evident that electricity promises much as a prime mover. In an economical point of view, of course the utilisation of water and wind power will be the most advantageous, although several conditions may arise in which the transmission of steam-power will be also admissible.

We cannot better conclude the discussion of this subject, which is one of world-wide importance, than by quoting from the address that Sir W. Armstrong gave before the Mechanical Section, at the meeting of the British Association at York in 1881. Sir William has himself utilised a waterfall on his own estate to drive dynamo-electric machines for the purpose of conveying power to a distance. He remarked :—

"But while still looking to heat as the fountain-head of our power, we may very possibly learn to transmute it, economically, into the more available form of electricity. One method of transformation we already possess, and we have every reason to believe there are others yet to be discovered. We know that when dissimilar metals are joined at opposite ends, and heated at one set of junctions while they are cooled at the other, part of the heat applied disappears in the process, and assumes the form of an electric current. Each couple of metals may be treated

as the cell of a voltaic battery, and we may multiply them to any extent, and group them in series or in parallels, with the same results as are obtained by similar combinations of voltaic cells. The electricity so produced we term thermo-electricity, and the apparatus by which the current is evolved is the thermo-electric battery. At present this apparatus is even more wasteful of heat than the steam engine; but considering the very recent origin of this branch of electrical science, and our extremely imperfect knowledge of the actions involved, we may reasonably regard the present thermo-electric battery as the infant condition of a discovery, which, if it follow the rule of all previous discoveries in electricity, only requires time to develop into great practical importance. Now if we possessed an efficient apparatus of this description we could at once apply it to the steam engine for the purpose of converting into electric energy the heat which now escapes with the rejected steam, and the gases from the fire. The vice of the steam engine lies in its inability to utilise heat of comparatively low grade, but if we could use up the leavings of the steam engine by a supplemental machine acting on thermo-electric principles, the present excessive waste would be avoided. We may even anticipate that in the distant future a thermo-electric engine may not only be used as an auxiliary, but in complete substitution of the steam engine.

"But it is not alone in connection with a better utilisation of the heat of combustion that thermo-electricity bears so important an aspect, for it is only the want of an efficient apparatus for converting heat into electricity that prevents our using the direct heating action of the sun's rays for motive power. In our climate, it is true, we shall never be able to depend on sunshine for power, nor need we repine on that account so long as we have the preserved sunbeams which we possess in the condensed and portable form of coal, but in regions more favoured with sun and less provided with coal, the case would be different. The actual power of the sun's rays is enormous, being computed to be equal to melting a crust of ice 103 feet thick over the whole earth in a year. Within the tropics it would be a great deal more, but a large deduction would everywhere have to be made for absorption of heat by the atmosphere. Taking all things into account, however, we shall not be far from the truth in assuming the solar heat, in that part of the world, to be capable of melting annually, at the surface of the ground, a layer of ice 85 feet thick. Now let us see what this means in mechanical effect. To melt 1 lb. of ice requires 142·4 English units of heat, which multiplied by 772 gives us 109,932 foot-pounds as the mechanical equivalent of the heat consumed in melting a pound of ice. Hence we find that the solar heat operating upon an area of one acre, in the tropics, and competent to melt a layer of ice 85 feet thick in a year, would, if fully utilised, exert the amazing power of 4,000 horses acting for nearly nine hours every day. In dealing with the sun's energy we could afford to be wasteful. Waste of coal means waste of money, and the premature exhaustion of coal beds. But the sun's heat is poured upon the earth in endless profusion—endless at all events in a practical sense, for whatever anxiety we may feel as to the duration of coal, we need have none as to the duration of the sun. We have therefore only to consider whether we can divert to our use so much of the sun's motive energy as will repay the cost of the necessary apparatus, and whenever such an apparatus is forthcoming, we may expect to bring into subjection a very considerable proportion of the 4,000 invisible horses which Science tells us are to be found within every acre of tropical ground.

"But whatever may be the future of electricity as a prime mover, either in a dominant or subordinate relation to heat, it is certain to be largely used for mechanical purposes in a secondary capacity, that is to say, as the offspring instead of the parent of motive power. In transmission to a distance the cost of the conductor will, however, be a grave consideration where the length is great, because its section must be increased in proportion to the length to keep the resistance the same. It must also be large enough in section to prevent heating, which not only represents loss, but impairs conductivity. To work advantageously on this system, a high electromotive force must be used, and this will involve loss by imperfect insulation, increasing in amount with the length of line. For these reasons there will be a limit to the distance to which electricity may be profitably conveyed, but within that limit there will be wide scope for its employment transmissively. Whenever the time arrives for utilising the power of great waterfalls the transmission of power by electricity will become a system of vast importance. Even now small streams of water inconveniently situated for direct application may, by the adoption of this principle, be brought into useful operation.

"For locomotive purposes also we find the dynamo-electric principle to be available, as instanced in the very interesting example presented in Siemens' electric railway, which has already attained that degree of success which generally foreshadows an important future. It forms a combined fixed engine and locomotive system of traction, the fixed engine being the generator of the power and the electric engine representing the locomotive.

"Steam power may both be transmitted and distributed by the intervention of electricity, but it will labour under great disadvantage when thus applied, until a thoroughly effective electric accumulator be provided, capable of giving out electric energy with almost unlimited rapidity. How far the secondary battery of M. Faure will fulfil the necessary conditions remains to be seen, and it is to be hoped that the discussions which may be expected to take place at this meeting of the British Association will enable a just estimate of its capabilities to be formed. The introduction of the Faure battery is at any rate a very important step in electrical progress. It will enable motors of small power, whatever their nature may be, to accomplish, by unin-

terrupted action, the effect of much larger machines acting for short periods, and by this means the value of very small streams of water will be greatly enhanced. This will be especially the case where the power of the stream is required for electric lighting, which, in summer, when the springs are low, will only be required during the brief hours of darkness, while in winter the longer nights will be met by a more abundant supply of water. Even the fitful power of wind, now so little used, will probably acquire new life when aided by a system which will not only collect, but equalise, the variable and uncertain power exerted by the air.

"In conclusion I may observe that we can scarcely sufficiently admire the profound investigations which have revealed to us the strict dynamical relation of heat and electricity to outward mechanical motion. It would be a delicate task to apportion praise amongst those whose labours have contributed, in various degrees, to our present knowledge, but I shall do no injustice in saying that of those who have expounded the modern doctrine of energy, in special relation to mechanical practice, the names of Joule, Clausius, Rankine, and William Thomson, will always be conspicuous. But up to this time our knowledge of energy is almost confined to its inorganic aspect. Of its physiological action we remain in deep ignorance, and as we may expect to derive much valuable guidance from a knowledge of Nature's methods of dealing with energy in her wondrous mechanisms, it is to be hoped that future research will be directed to the elucidation of that branch of science which as yet has not even a name, but which I may provisionally term 'Animal Energetics.'"

CHAPTER XVIII.

THE BRITISH POSTAL-TELEGRAPH SYSTEM.

THERE is no branch of the public service that has conferred on commerce, and society at large in this kingdom, such benefits as the existing Postal-Telegraph System. Under the management of the old rival companies telegraph work was badly done, but heavily paid for. Added to this was the rampant evil of the monopoly they possessed, and the consequent apathy, not to say insolence, with which the public was treated. The internal management of each company was often at the mercy of men who little understood their business, improvements were slowly adopted, there was no uniformity of charge, which varied according to distance at from one to six shillings; and in respect to speed of transmission and delivery, the ordinary post-office did better in many cases. The public, but especially commercial men, grew tired at this state of things, and at last there was a general feeling that it was the duty of the Government to take the whole system into their hands and purchase the rights of the company, whatever they might cost. To give some idea of the state of matters, the following remarks, which were penned by the Editor of this work in 1868, may be at least of historical interest:—

"In respect to the intended working of British telegraphs by government, in the preamble of the Bill introduced by the Chancellor of the Exchequer, it is recited, 'Whereas, it would be attended with great advantage to the State, as well as to merchants and traders, and to the public generally, if a cheaper, more widely extended, and more expeditious system of telegraphy were established in the United Kingdom; and to that end it is expedient that her Majesty's Postmaster-General be empowered to work telegraphs in connection with the administration of the Post-office.'

"It is, of course, a self-evident truth, that 'a cheaper, more widely extended, and more expeditious system of telegraphy' would be of immense advantage to the State, merchants, and the general community; but it will not be so easily conceded that all this is to be attained by simply transferring the administration of telegraphs from the present boards of direction of competing companies to a government official.

"Of course it would be quite possible for the government to extend the lines, and even reduce the price, since they have not to earn a dividend for shareholders; but that a *more expeditious system of telegraphy* shall, at the same time, be provided, without making the telegraph a heavy yearly tax on the country, is simply promising great things, which we have not the slightest reason for believing can be brought about by merely placing all our telegraphic lines in the hands of an official of the Post-office. (This was the generally accepted view, but has been utterly falsified by the fact that the British Telegraph system is now a source of great net profit to the revenue.)

"A telegraph is not capable of conveying an unlimited number of messages per day, and therefore there is a limit as to price at which messages could be sent remuneratively on any given circuit, even supposing that the wire was kept in constant work during the twenty-four hours. For such constant use, however, of one wire throughout the twenty-four hours, we must suppose the messages arriving for transmission

in continuous succession, or else *some must wait.* In practice, however, the great mass of messages are given in between business hours—say between 10 A.M. and 5 or 6 P.M. Sufficient wires must be provided, therefore, so that this mass shall be all despatched within those hours; the wires remaining idle, or nearly so, during the rest of the twenty-four, or else messages must be delayed in order to spread them over the twenty-four hours. It is evident that the first method cannot be adopted at the same prices as the second, since it involves three times the number of wires required for the second. In fact, just as we reduce the price of messages, so we must either decrease the profit or increase the average delay. Assuming that the dividend earned by our present companies, therefore, is a fair one, it is evident that to decrease the price we must decrease the average expedition with which messages are despatched, unless we can find some means of actually decreasing the time occupied in sending a message.

"Mechanical manipulation, long ago proposed, experimented on, and rather carelessly abandoned, but now perfected by Wheastone in his automatic telegraph, is a great step in this direction; and, no doubt, when adopted throughout the principal circuits, will enable a reduction of price to be effected. But this improvement (the benefit of which we shall have, whether the government obtain their bill or not) is entirely a scientific one; and, indeed, as we have shown, the only hope of decreasing the price of telegraphing in England must be by means of scientific improvements such as these."

The above remarks must amuse our readers. They are simply a reflex of opinion universally held in 1868. How little do they accord with the facts of the present day, and the results which have been achieved by science in a time when we can send four messages simultaneously in opposite directions by the same wire, and even by the telephone speak in our own voice to friends miles away!

We have already stated that the old companies did their business badly. As an illustration of this we give an extract from a work by Mr. Stephens on *The Transferrence of the Telegraph to the State.* Addressing the then telegraph operators of the companies, he remarks:—

"If each and all of you were to speak the truth —the whole truth—the mispronunciations of 'High Life Below Stairs,' the mis-spellings of Artemus Ward, the keen flashing wit of Sidney Smith, the playful humour of Charles Lamb, the burning sarcasm of Douglas Jerrold, the bitter satire of Thackeray, and the grim sneers of Carlyle, fall far short of what you have done. For obvious reasons, the *creme de la creme* of your doings must be kept secret, rolled as sweet morsels under the tongue, and laughed over by *confrères* only in private. But some few have been made public in one quarter, giving full exercise to that faculty of mirth which Ruskin, in his beautiful and anything but mirthful way, tells us should be cultivated as assiduously as other faculties. Royal palace, as well as mercantile counting-room, has pealed with merriment at your expense. Some official, other than telegraphic, let out that little affair of yours from a certain place, about transmuting 'I have not heard from you for ages,' into 'I have not heard from you for Agnes;' and how, from another place was flashed the indignant reply that 'Agnes' was an utter stranger. You have amazed a husband on his travels by informing him that he was the father of a dolphin. You extinguished (distinguished) a man in Paris with an enormous red cockade; made Italy pregnant with a lamb (alarm); sent a man a train filled with penny shovels (perishable goods); told one man that his onions (opinions) were not wanted; made travellers inform their masters that they could not leave London without their cabbage (luggage); asserted that sugar-cans (canes) grew in Jamaica; that seraphs (serfs) were emancipated in Russia; said that the Emperor of Austria gave ambassadors a spree (*soirée*); made Captain Smith, of her Majesty's 33rd, indignant by addressing him as Captain Smith, of her Majesty's dirty 3rd; caused Mrs. Smith to have a 'scene' with Mr. Smith about that interview at a late hour with a brother merchant; amazed a distinguished poet by consigning to him a cargo of codfish and salt pork; and amused a distinguished clergyman by asking him his lowest offer for steam coals; raised the price of monkeys on the coast of Africa, and caused 'a run' on parrots in Melbourne; led a bankrupt to be stripped half-naked by demanding a rigid examination into his state (estate); nearly got a merchant into the 'black list' by saying that he was nowhere (now here); and Mr. Johnston reminds us how you telegraphically hawked a message, addressed 'La Reine d'Angleterre,' all over the country in vain; and were about to intimate by post, to an illustrious personage abroad, that there was no such person in this country as the 'Queen of England,' till the idea struck one of you that we ourselves might know some ship captain of that name in a certain port which, since the days of George IV., has never had an opportunity of offending the nostrils of royalty. Happening to know both the name and address of 'our Most Gracious Lady,' we gave instructions which led to its delivery.

"But your jokes are nothing to some of your 'sells,' many of which must also, for obvious reasons, be kept secret. The blinding tears of irrepressible laughter roll down our cheeks as we think of some of the Sancho Panza capers which you have made staid and sober men cut, and of the Quixotic expeditions upon which you have sent wise people, great physicians among the rest, who, if they had dissected some of your brains, might have found the connecting link between man and the gorilla."

This racy description of the errors of the telegraphist must, of course, be taken *cum grano salis;* although, from personal experience at that period, the "grain," we believe, might be very small in certain cases. We have watched, for hours together, the telegraphic communication kept up at leisure between telegraph clerks when the wires were unused for

business purposes; and must confess that, by the whims and caprices of the arrangement, some laughable mistakes occurred. Of course, business matters are equally subject to the same sources of error; and, in more than one instance, such have resulted in serious consequences. As a rule, however, considering how careless many persons are in not only writing the original telegram, but even in addressing letters transmitted by post, the wonder is how so few errors are made by the telegraphic agents.

The concluding remarks remind us of the ignorance of the public about the actual method of working the telegraph. The following anecdote, that we vouch for by personal experience, may illustrate some of the difficulties under which telegraph clerks laboured.

A friend, well known as an eminent composer of music to many of our readers by name, desired to telegraph from Glasgow to Brighton his wishes in respect to the funeral of a relation, of whose sudden decease he had notice by telegraph. Accompanying him to the telegraphic office at the Exchange, Glasgow, we wrote out on the usual telegraph paper, supplied at the office, his requests. The handwriting, perhaps, was scarcely so good as it ought to have been, consequently our friend remonstrated, stating that what we had written would *be sent by the wires, and, possibly, his correspondent would not be able "to make it out."* Had our friend attempted "to telegraph" himself, he would have done it verbally, if possible; for he was utterly ignorant of the fact that a written message was then sent by signals. In fact, he had the idea in his head that the message written on paper was transmitted by that paper through or on the telegraph wires. One would scarcely suppose that an intelligent man could make such a mistake; but the back scenes of telegraphy reveal many *faux pas* of human intelligence. It is not a matter of surprise that persons of inferior intelligence at that time have been known to request the clerks to telegraph (not for) an umbrella, etc., etc.

We have spoken of defect as regards speed of transmission and delivery. But the telegraph companies were awakened to a sense of their shortcomings in this respect. Fortunately for them, Sir Charles Wheatstone came to their rescue, and culminated his previous inventions by one of which the following is a brief description, namely, the—

"*Automatic Telegraph*, which is now extensively worked with much success by the Electric Telegraph Company, and the rate of speed attained by its means is perfectly marvellous. The messages are punched out upon strips of paper, and are sent with a rapidity far exceeding the manipulative skill of the most experienced operators. The punching system was introduced by Bain in 1848; but it was never practically employed, owing principally to the coarse nature of telegraphs in those days, both in the construction of apparatus and the erection of lines. Sir Charles Wheatstone has, however, reduced the construction of telegraph apparatus to a condition of beauty and finish only exceeded by the delicate workmanship of the chronometer or watch maker; and our numerous telegraph engineers, Clark, Varley, Culley, etc., have so far improved the construction of our English telegraphs, that there is little left to be desired either in efficiency or durability. The automatic instrument works with a speed and regularity between London and the North that a few years ago would have been absolutely impossible. Neither rain nor wind, fog nor snow, offer obstacles to this delicate apparatus; but night and day, through sunshine and storm, it does its work with a regularity and efficiency that is highly creditable to its gifted inventor, and to the maintainers of our telegraph communication.

"A great improvement has recently been effected by Mr. Culley, the indefatigable and zealous engineer of the Electric Telegraph Company, in the preparation of the punched paper ribbon. In the ordinary way, the punches are struck by pieces of vulcanite held in the hand; but Mr. Culley has placed above each punch a small cylinder containing a piston, acted upon either by vacuum or compressed air. The use of the pneumatic apparatus throughout the great building of the Telegraph Company in Telegraph Street enables this plan to be adopted with great ease. The valves are worked by finger-keys as light in their touch as those of a pianoforte. The softer sex, who operate these instruments in Telegraph Street, have their labour rendered as gentle as their natures. Punching is effected with the greatest ease, and with much more rapidity than before."

At last, at an enormous expense the Government acquired the rights of all the Telegraph Companies of the United Kingdom. We have little hesitation in saying that the nation was well fleeced by the companies and their officials. The demands for compensation by the latter were at times ludicrous. In one instance, we remember, an official asked the Government to grant him some compensation on the ground that his company allowed him first-class fare, while he only travelled second, so that by leaving the company compulsorily he would be an annual loser! It was generally thought that from four to five millions would have covered all the expense. But this idea was utterly fallacious, as the following extract from the Postmaster-General's report for 1880-81, published in August, 1881, will show.

"The capital sum raised for the purchase of the Telegraphs since 1869 exceeded ten millions sterling, and hitherto the results of the undertaking have exhibited an annual deficiency of interest amounting in the aggregate to not less than £1,216,000. For the first time, however, the net telegraph revenue for the year (1880-81) viz., £328,878, has been sufficient to pay the full interest, 3 per cent., on the capital, and leave a real surplus of £2,462 towards the cancelling of debt."

The Post-office authorities within a few hours of their coming into possession of the telegraphs found out the difficulties they had to contend with. In a majority of cases the instruments

throughout the country were in a defective condition. In respect to the operators the less said the better. Conversing with a friend who had previously established a large school of telegraphy in the north of London, a telegram was put into our hands in the afternoon of the day preceding that on which the Government were to commence operations. It is unique in its character, was sent from the head office, and as a specimen of telegraphy early in the year of grace 1870 we reproduce it *verbatim.*

"Send here all your *mail* clerks at once," from which it would appear that the operator was more conversant with the postal mails than with the *male* sex of his fellows.

As many as could be got together were accordingly sent off to the city. They returned almost immediately, and had to start to Yorkshire and other distant places at moment's notice, and with no clothing beyond that which they were at the moment wearing. This will give the reader some idea of what telegraphy was under the *régime* of the old companies, yet we must add, but a very slight idea of the then state of things.

The clerks or operators, in fact, were chiefly the nominees of directors and others, and all of the male sex, with but little exception. Since the Government have had matters in hand a school of telegraphy has been formed, and consequently, at the present day, only qualified operators of first-rate ability are appointed.

The education required by telegraphic assistants should not only comprise the ordinary branches of education, but also a considerable knowledge of mathematics, including algebra and the elements of geometry, natural philosophy, and chemistry; and especially in the scientific department will a thorough acquaintance with the laws of electricity, magnetism, and electro-magnetism be desirable. It is always of great advantage to the operator to know the "why" and "wherefore" of the action of the instruments he employs, not only for remedying temporary defects, but also in the highly possible chance that such a knowledge may lead to new discoveries. All the improvements that have originated in telegraphic apparatus, have arisen from the hands of practical men well acquainted with science. As the historical portion of our subject, in a previous chapter, shows, the progress of telegraphic improvement has been very rapid during the last thirty years, whether as regards extension, accuracy, or speed; and all such improvements, as they have arisen, have laid the foundation for fresh ones, that have been, and will be, made by thoroughly experienced telegraphists. Any of our readers, therefore, who may propose to enter the telegraphic service, should, of all things, study the subject experimentally; for this alone will give expertness and readiness in operating. For a moderate expense, and by simple apparatus described in the preceding pages, any one may soon gain an adequate scientific knowledge. It is often an advantage, rather than otherwise, for a beginner to meet with difficulties in the pursuit of experimental science; for then his inventive powers are called out, and he is caused to rely on his own resources. Nearly all the great discoveries in natural philosophy and chemistry have been made with the simplest apparatus; and, therefore, none need despair of progress if a little energy and self-determination, with industry, be resolved on as a habit and practice.

Under the guiding hand of Mr. Frank Ives Scudamore, to whose patient perseverance the present condition of the British Telegraph System is mainly due, the errors of the old companies were gradually obliterated. A uniform charge of one shilling for twenty words was established throughout the kingdom, and thus the telegraph system became a social institution, second in importance only to that of the Post-office itself, and still better because a paying concern. The statistics which we give as follows and throughout this chapter have been drawn from official accounts with which we have been kindly furnished.

In the first place we may draw attention to the rapid increase which has attended the present system since its inauguration in 1870-71. In that year the total was in round numbers 10,000,000, while in 1880-81 the total amounted to about 30,000,000. The number for each year is given in the table at p. 595.

In former times, by far the greater portion of the messages sent by telegraph were entirely of a commercial character. But since the reduction of charge and the improved service that has been substituted the use of the telegraph has largely increased. We found some sixteen years ago, in looking over the telegrams sent from one of the largest towns in England, that out of 6,000 only 200 were exclusively for private purposes. Now, the telegraph is used for comparatively trivial purposes. Another great boon which has been conferred on commerce, has been the arrangements for the use of private wires, by which the counting-house in the City and the factory at any distance, within the metropolitan area, may be kept in constant communication at a mere nominal cost. In 1870-71 only 776 contracts had been entered into, running over a length of 2,587 miles, and including the use of 1,971 instruments, while in 1880-81 there were 1,945 contracts, 9,055 miles of wire, and 6,326 instruments in use entirely for private individuals. While in 1870-71 the revenue obtained from this source was but £22,574, in 1880-81 it had amounted to £74,533.

For the purpose of conveying messages throughout the kingdom, but especially in large towns, overhead wires have been used. At one time they were exclusively employed. But now subterranean wires are largely used. The overhead wires are constantly liable to derangement from weather, malice, and other causes. On more than one occasion in London, the breakage of them has caused fatal accidents in the thoroughfares. Of recent years, therefore, the underground system has been adopted, a fact with which most of our readers residing in London must be familiar, by noticing the continual repairs, involving the taking up of the

Table showing the Total Number of Messages forwarded from Telegraph Offices in England and Wales, Scotland, and Ireland, in each year since the transfer of the Telegraphs to the State.

Year.	Number of Messages.					
	England and Wales.			Scotland.	Ireland.	TOTAL.
	Provinces.	London.	Total.			
1870-71..	5,299,882	2,863,821	8,163,703	1,080,189	606,285	9,850,177
1871-72..	6,594,590	3,612,772	10,207,362	1,388,434	878,000	12,473,796
1872-73..	8,022,151	4,577,015	12,599,166	1,761,298	1,175,316	15,535,780
1873-74..	9,233,854	5,254,547	14,488,401	2,009,893	1,323,236	17,821,530
1874-75..	10,124,661	5,652,033	15,776,694	2,132,787	1,343,639	19,253,120
1875-76..	10,883,282	6,350,714	17,233,996	2,287,359	1,452,180	20,973,535
1876-77..	11,232,704	6,561,930	17,794,634	2,402,347	1,529,162	21,726,143
1877-78..	11,392,098	6,700,504	18,092,602	2,490,776	1,588,489	22,171,867
1878-79..	11,592,899	8,830,019	20,422,918	2,477,003	1,559,854	24,459,775
1879-80..	12,392,996	9,854,566	22,247,562	2,704,574	1,595,001	26,547,137
1880-81..	13,574,608	11,613,389	25,187,997	3,042,291	1,736,677	29,966,965

The figures for each year since 1877-78 include the number of certain Press Messages not previously included in these Returns.

wires at the edge of the pavement. Although the troughs containing the wires are kept as close as possible, still moisture passes through, the insulating material of the wires gets destroyed, and the conducting power of the wires impaired.

There is now, therefore, a growing tendency to substitute underground for overhead telegraph lines, principally because of their immunity from interference, whether in times of peace or war, or the designs of malice. Subterranean wires have been preferred to aërial ones by the German Government for the connection of their fortresses and chief towns, and their example has been partly followed by the French Telegraph Administration. England, too, is recognising the greater advantage of a line protected by the soil, and it is not improbable that we shall soon have some of our main aërial circuits replaced by buried cables. The snowstorms of the winter of 1880-81, which devastated the line of Aberdeenshire, and necessitated the sending of a message round by Scandinavia to get to its destination, but a few miles from its starting-point in Scotland, gave a lesson which will not soon be forgotten, even though the occasion was unusual. Given a good and inexpensive subterranean cable, and the advantages it possesses over aërial wires, are sufficient in due time to make themselves felt. Such a cable, if we may judge from actual experience, already exists in the invention of Mr. David Brooks, of Philadelphia, and there is evidently a useful future in store for it as a telephone line for cities, and also, perhaps, a conductor for trunk circuits in ordinary working. We are indebted for its description and illustration to *Engineering*:—

The two chief insulators hitherto employed for cables, namely, gutta-percha and india-rubber, are both solids; but the distinctive feature of Mr. Brooks's system is the use of liquid petroleum oil. Faraday proved long ago that oils were insulators, but the practical difficulties in applying them have doubtless prevented their employment as such. These difficulties have been overcome by Mr. Brooks in a very simple, and at the same time effective manner, so that for the first time in the history of telegraphy the liquid insulator has been adapted to everyday service.

The term petroleum conveys to most people the disagreeable idea of explosiveness, and when the Brooks system was first brought to the notice of the French Telegraph Administration, there were some natural fears that it would be

dangerous to employ it in Paris, where the underground lines are laid in the sewer passages. But any alarm on this score is baseless, for the "petroleum" used by Mr. Brooks is the residual oil left behind after the inflammable oils have been driven off in the process of distillation. It is not at all inflammable, and is ordinarily used for lubricating purposes. The general mode of employing it by Mr. Brooks for cables is to confine it in a metal tube laid underground, and thread the conductors through the tube among the oil.

Each copper wire, say No. 18 gauge, is covered with a serving of jute or Manilla hemp to prevent them from touching one another. Lengths of 1,000 feet to 2,000 feet are then twisted together into a strand cable bound together by a hempen twine in a single lay. Thirty, forty, a hundred, or more of these wires may be banded in this way and laid within the same pipe, the oil permeating the whole mass and insulating them from each other. The pipe is of cast iron galvanised, about $\frac{1}{8}$ inch thick in the metal. The pipe is made in lengths of 15 feet, united together by conical screw-joints, the threads of which are filled with shellac gum. Joint boxes for connecting up different lengths of cable are inserted at every 1,500 or 2,000 yards.

The box is about three inches in diameter, and screws off, allowing the two ends of the sections of cable to be brought out. The copper conductors being then bared, are simply twisted together for about $3\frac{1}{4}$ inches and the joint is made. No solder is necessary if the jointer's hands be clean, for the oil is an excellent preventive of oxidation of the wire and fouling of the joint. To further insure a good contact the precaution is taken to tin the copper wire, and the twist is wrapped with tape.

In the operation of jointing no attention is paid to joint the opposite and corresponding wires of the two sections together. Indeed, those wires which are not opposite to each other are purposely joined together, in order to eliminate as much as possible the induction effects which perturb telephonic communication. The very presence of a considerable number of circuits lying close together helps to weed out this disturbance, for it has been found that when a number of wires in a cable are used for telephone working, the inductive influence between wire and wire appears to diminish in proportion to the number of wires in the pipe, a result due, in all probability, to the distribution of the effect around the particular wire employed. But in addition to this result of mere contiguity Mr. Brooks, by joining the wires of each section of cable promiscuously together, or rather the outside wires to the inside ones designedly in each case, obtains the further advantage of a long twist in the several circuits. It is well known that two wires twisted round each other do not suffer so much from mutual induction as if they were drawn side by side. Mr. Brooks's plan of cross-connecting the wires at each joint has also the neutralising effect of twining them together.

Both experience and experiment have demonstrated that the Brooks subterranean cable may be used with great advantage for telephone work. A single wire of the cable in operation between Waterloo and Nine Elms has been employed as a telephone circuit for some time, and although the other 29 wires of the cable are heavily worked by the ordinary telegraphic currents, the inductive interference has not been such as to cause inconvenience. A telephone (we are told by one of the Post-office electricians) placed on two wires of the entire length between Waterloo and Clapham did not emit any sound, although a Wheatstone automatic instrument with high battery power was being worked on one of the wires. Moreover, in the short sample of cable exhibited at Paris the intermittent current from a small magneto-electric generator when sent through one of the circuits did not make itself heard on a telephone connected with one of the neighbouring wires. These are severe tests, and fully illustrate the immunity of Brooks's system from induced perturbations, an immunity which is probably due not only to the number of circuits lying in close proximity, and the way in which they are cross-connected at intervals, but also to the fact that the iron pipe serves for a common return wire.

When the ends of the wires are joined together in the joint-box, the latter is filled up with oil and made tight with a screw plug. The object of the reservoir of oil, which is placed at the highest point of the line, is to give a head of oil sufficient to produce a pressure in the pipes which will exclude the moisture of the earth. At Clapham Railway Station, from whence there is a line working to Queen's-road, a distance of 7,000 feet, the reservoir contains about two barrels of oil, and the head obtained is about 6 feet above the level of the line. At Waterloo the head is 10 feet, but if the pipes are to be laid under water a higher head should be adopted. Besides giving the necessary head of oil, the reservoir, which is open to the air, also supplies any slight loss of oil by leakage from the pipes, and gives freedom to any expansion or contraction of the insulator due to variations of temperature.

Where the conductors are brought out of the pipes to be attached to the telegraphic instruments, short lengths of india-rubber-covered wire are spliced to each, and led through a terminal box or tube tightly filled with solid paraffin in order to cover the joints and prevent any escape of the oil. This terminal box is, therefore, a necessary adjunct. There and at the joint-boxes the moisture of the hand which has been left upon the wires in the act of splicing is driven off by heating the oil to a temperature of 300 degrees Fahr. for half an hour; and the cement employed for the joints of the pipe is silicate of soda, which becomes a species of glass by the heat. We should also add here that in Paris, where the pipes run in the sewers, lead is used for jointing instead of shellac, which does not stand the water so well.

Brooks's system of subterranean conductors

has been in successful operation in the United States for more than four years, and it has now gained a footing in several parts of Europe. A short length has been tried experimentally by the Post-office on the South-Western Railway between Waterloo and Nine Elms, since September, 1880, and we understand that not one of the wires has been interrupted, while the cost of maintenance has been practically *nil*. This result determined the Post-office to further extend the system from Nine Elms to Clapham. The extended line from Nine Elms to Queen's-road, a distance of 5,800 feet, consists of 30 No. 78 copper wires, each served with jute and spun into a cable. From Queen's-road to Clapham, a distance of 7,000 feet, the cable is formed of 40 wires of the same gauge also served with jute, but the same calibre of pipe answers for both.

The insulation resistance of these lines at normal temperature is between two and four megohms per mile, and the electrostatic capacity for the same length is from 0·3 to 0·4 microfarads. As pointed out by Faraday, the lower electrostatic capacity of liquid as compared with solid insulators, gives them an advantage for telegraph work, as tending to produce less retardation of the signals, and consequently a higher speed of telegraphing. This insulation resistance is low as compared with that of gutta-percha or india-rubber core, but in a practical sense that is really an advantage. It is not well known, except to cable electricians, that a slight fault or excess of leakage in a cable diminishes the retardation of signals and produces greater speed of working; and there is a mistaken idea abroad that the higher the insulation resistance of a cable the better it is for signalling. This is true in so far as it prevents loss of the electric current, and consequent enfeebling of the signals. But this high insulation is generally accompanied by a high electrostatic capacity which operates in retarding the progress of the signals along the cable. A slight fault at an intermediate point of the cable acts like a partial "earth," reducing the theoretical length of the cable, and as the speed of working is inversely proportional to the square of the length, the result is that the fault increases the rate of working. "Faults" or flaws in the insulating material are, however, dangerous things, as they may at any moment get larger, and ultimately make a "dead earth," carrying off all the current before it reaches its destination at the other end of the line. It is not, therefore, advisable to tolerate their existence. But in the case of Mr. Brooks's cable the low general insulation seems to act like an infinite number of minute faults throughout the whole line, and the result is a higher rate of speed than an india-rubber or gutta-percha core could give. A low insulating gutta-percha core would be a bad gutta-percha core, and, therefore, unsafe to use, but with Mr. Brooks's system lowness of insulation is quite consistent with durability. It simply depends on the quality of the oil employed; and the degree of insulation can be varied at will by changing the oil with the help of a syphon. Mr. Preece is fully alive to the advantages of the Brooks system in this respect, and foreign electricians are also beginning to recognise them, although at first they stipulated for an insulation as high as 200 megohms per mile.

As yet no satisfactory coefficient for calculating the alteration in resistance of Brooks's insulator by change of temperature has been determined. The change differs, however, with the quality of the oil and the jute serving employed. The higher kinds of oil have a greater coefficient of change than those of lower quality, a fact which is analogous to the behaviour of gutta-percha. Mr. Brooks states that the coefficient for oil and jute combined is but one-half of that for oil alone, and that the insulation resistance of the cable doubles itself for every 20 deg. Fahr. of fall in temperature.

Besides London and America, Brooks's subterranean line has been tried at Brussels, and from Paris to Nancy. The results of the latter trial have determined the authorities to extend the system. The system combines a number of advantages over gutta-percha, and has evidently a prosperous career before it. It is more durable than gutta-percha, cheaper, and less liable to interruptions from accidental causes, besides offering less retardation to fast-speed telegraphing. As compared with overhead lines it is freer from injury due to weather changes or the tampering of animals and man. Moreover, it is safer to life and limb in large cities than house-top wires, and for telephone work especially, it has the merit of silencing those obtrusive sounds due to the induction of neighbouring circuits.

In regard to the work done for newspapers, the amount of telegrams is now enormous. In respect to speed it can hardly be excelled. One of the most recent examples of speed and accuracy occurred in October, 1881, during the visit of the Right Hon. Mr. Gladstone to Leeds, of which the following is an account:—

"The resources of the telegraph department at the Leeds Post-office were most heavily taxed during the visit of Mr. Gladstone. The ordinary staff, however, without any assistance, proved itself to be quite equal to the emergency, and did its work in a manner which places the Press under deep obligation. On the first day of the Premier's visit (Friday) no less than 447,274 words were transmitted over the wires to telegraphic circuits in the kingdom. This is the largest total of words ever despatched by wire from one office on one day. Although a large portion of the messages were handed in at a late hour in the evening, the bulk of the traffic was cleared off by shortly after eleven o'clock. The weather, it should be stated, was very unfavourable for telegraphing. The heavy rain interfered with transmission to Plymouth and other distant towns on Thursday night, the evening of the Premier's arrival at Leeds. On Saturday, the second day of the demonstration, the number of words telegraphed was 207,279, bringing up the total number of words transmitted in connection with the event to 654,553.

In addition to the extensive arrangements which are ordinarily made for exceptionally busy occasions, fifteen extra Wheatstone automatic circuits were established on both days. The pressure was not so great on Saturday, owing to the fact that a large number of reports were forwarded by train to London and other towns."

The general management of the telegraph department is now carried on in a new building erected opposite the old Post-office in St. Martin's-le-Grand, London. As few are allowed entrance into it, the following results of a personal visit may be of interest. At the basement are powerful steam-engines which pump air into receivers. This compressed air is used to propel packets of telegrams to the chief districts in and about the City through pipes laid under the pavements of the chief thoroughfares. This arrangement has already been described at a previous page. It saves all telegraphing by instrument within the district traversed, which at present is but a little over a mile from the central office, so far as telegrams passing within those limits are concerned. On the first and other floors are rooms for the officials. A large room is devoted to the repair and manufacture of the instruments, which are chiefly the single needle and an improved form of Morse, each of which have been fully described in preceding pages. But the top of the building has the most imposing effect. Here are seated a great number of young ladies, who sit in front of a table to receive or send messages. Each table is labelled with the town whose wires are connected with it, for example, Manchester, Leeds, etc., etc. The sight, altogether, is unique and striking. Silence reigns supreme in the room, so far as human voice is concerned, although, during the day, thousands of persons are conveying their wishes silently through the wires. On one side the pneumatic tubes, connected with the district offices, are placed, with openings to receive or deliver the messages sent, as already stated, within the London district.

We thus see that the present British Postal-Telegraph System has been carried on in a manner which, while it is of great public utility, or rather necessity, is yet a source of profit to the National Treasury. Its progress yearly increases. In 1880-81, there were 107 new offices opened, making a total of 5,438 in the United Kingdom. The telephone, to which, with duplex and quadruplex telegraphy, we shall draw attention in the next chapter, is rapidly being extended through the agency of companies, and by the Post-office, thus enabling persons to actually talk with each other in their own voice by telegraphic wires. In 1881, the total staff of officers, engineers, clerks, telegraphists, messengers, etc., amounted to 11,410. As already stated, the number of offices open was 5,438, of which 4,015 were open at post-offices, and 1,423 at railway stations. Altogether, we may consider our present telegraph system as a credit to the business, tact, and character of our country, and a striking example of what science may do for us in meeting the exigencies of our daily life, whether commercial or social.

CHAPTER XIX.

THE TELEPHONE, MICROPHONE, DUPLEX AND QUADRUPLEX TELEGRAPHY.

IN the preceding pages we have drawn attention to all the most important facts, details, practice, etc., of telegraphy, both on land and water. Some special details, however, have been reserved, because they hardly fall for the present under the category of every-day practice, so far as the popular idea is concerned. These include the inventions of the telephone, microphone, and the practice of duplex and quadruplex telegraphy. Indeed, in a scientific point of view, they are comparatively novelties, and are only now in partial progress, so far as practice is concerned, in the ordinary telegraphy system. We shall take each subject in the order above stated.

THE TELEPHONE.

As the name suggests, to those acquainted with the Greek language, the word *telephone* means *distant-speaker*, or he whose voice can by some suitable means be carried to a distance so as to be heard by others. In the ordinary way, the atmosphere is the chief means of conveying sound, but artificial means, such as speaking-tubes, etc., are frequently had recourse to. But in the case of the telephone, electricity is employed for that purpose. The explanation of this appears at first sight very difficult, but if we patiently inquire into the cause of the production of sound, and secondly proceed from the old well-known methods of conveying, conducting, propagating, and in some cases increasing sound, the difficulty will gradually disappear, and the philosophy of the telephone and microphone will be easily understood; we hope, indeed, in the following pages, even by the unphilosophical reader, although in his case we shall have to ask careful attention to the facts we adduce, the reasoning we found on them, and the conclusion therefrom to be drawn.

The production of sound is so familiar that we need scarcely draw attention to it. We cannot, however, fail to notice that there exists a vast diversity in the sounds we hear. Thus, if a piece of wood or stone be struck, we simply notice a dull, heavy sound, entirely devoid of musical intonation, provided the bodies be struck in large irregular masses. If, however, they have certain definite shapes, and their lengths and thicknesses increase and diminish in definite ratios, then we hear graduated sounds. These may be produced by percussion—as in the case of the pianoforte, the strings of which afford "music" on being struck by the hammer; or by simple vibration, as we observe in the cornet, the flute, and other wind instruments.

Now, in any case where sound is produced, such results simply from the vibration of the particles of the body which gives it; and the common tuning-fork, perhaps, affords us the best illustration of this fact. If the fork be struck against any hard body, then its prong at once vibrates, and, in so doing, it causes the air next to it to vibrate also. We hence have a successive series of waves afforded, just as we observe the same effect produced on casting a stone into still water. Now, just as a succession of circles passes from the spot at which the stone arrived on the surface of the water, so the same result occurs when a sounding body is put into motion. This is illustrated, so far as sound is concerned, in the annexed engraving, which shows, by the dotted lines, the vibrations which the metal of the tuning-fork undergoes after percussion. The body, however, must be elastic to produce sound: thus a piece of clay scarcely affords sonorous waves, because it has but a very slight amount of elasticity. If, however, a glass vessel of any kind, which is elastic, be struck, it at once produces and propagates in the air a series of waves, or vibrations; and these reaching the ear, so far act on that organ as to make it sensible to the sounds produced. But to produce such a sound the body must be elastic throughout its texture. Now in the case of a cracked jar or other glass vessel this condition is not fulfilled, hence the vibrations produced are not identical in character with those afforded by a sound or unbroken vessel. In fact, in the case of glass, porcelain, and many other materials used for making domestic utensils, the sound produced by them on being struck is considered as a test of their value, consequent on their freedom from cracks or similar imperfections.

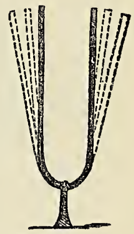


Fig. 295.

That an elastic body really vibrates when it is put into sufficient motion to produce waves of sound, is most readily proved. For this purpose, place a thin glass tumbler on any firm support, and hang a small wooden ball, by means of a thread, from any support, or by the hand, so that the ball may just touch the rim of the glass; then draw a violin bow against the rim of the glass. The vessel will thus be set into vibration; and the ball, resting against the rim, will be repelled, and oscillate for some consider-

able time. The mode of carrying out this interesting experiment is illustrated in Fig. 296; in which the straight line represents the cord holding the ball as suspended from any support, and the dotted line shows its vibration. The

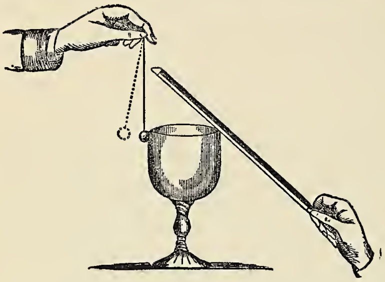


Fig. 296.

success of the experiment will depend on the glass rim being quite clean; and the bow should be well rubbed with rosin, to afford as much friction as possible.

To show how musical sounds in harmonic succession—a subject to which we shall have to draw attention in a special manner hereafter, in connection with the working of the telephone, and the defects which sometimes show themselves in that working—the following arrangement may be constructed:—

If eight finger-glasses, or tumblers, are placed on a hollow square box, and they be chosen so that they may have a relative size (of which we shall speak more fully hereafter), a series of musical sounds may be readily produced, which accord with an octave, or eight successive notes of any musical instrument. The sounds are given off on the edges of the glasses being rubbed by the finger, which has previously been wetted by a little lemon-juice, to give it a degree of roughness. The finger should be gently but firmly rubbed round the rim of each glass; and the arrangement of which we speak is illustrated in the following engraving—the octave succession of notes being also indicated. The effect produced by the action of the finger is exactly similar to that afforded by the bow in our last illustration. The glasses are caused to vibrate, and the production of sound is the natural result.

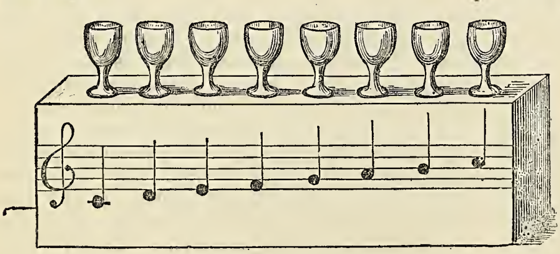


Fig. 297.

We might add, to a great extent, various illustrations of the production of sound of a musical kind, by means of vibrations of the atmosphere and solid bodies. The Æolian harp is an instance in which the air, moving through the intervals between wires of different thicknesses, produces such results. Even the wires extended on the poles observed by the sides of our railways, for telegraphic purposes, often afford, by their vibration, what we may venture to call a wild kind of music. The striking of a gong, and similar instruments, on the other hand, afford instances in which sound is produced by the vibration of solid bodies, subsequently propagated through the air. Wind instruments of all kinds produce these effects on the ear, by a combination of the vibrations of their solid parts with those of the surrounding atmosphere.

From what has been stated and illustrated it is evident that without vibrations there can be no sound produced. Now vibration, or motion in definite form or forms, seems to be at the foundation of all our knowledge of what have long been termed "imponderable agents"—that is, heat, light, electricity, and magnetism. In the preceding pages we have found that these forces are capable of producing each other, and so have an astonishing analogy subsisting between them. Fortunately for science the study of the laws of sound, which is embraced under the title of *Acoustics*, gives us in many cases a kind of clue to the study of the four forces just named, and hence it is essential, in explaining the telephone, that certain acoustic laws should be thoroughly understood; and equally necessary is it that in the construction and use of the instrument those laws should be carefully attended to. We next turn to consider—

The Conduction of Sound.

It has already been remarked that whenever vibrations are produced, affording sound, the waves of sound are propagated by the surrounding bodies; but this depends on the elasticity of those bodies, as many substances—to use a common phrase—stop sound: that is, they prevent its passage, being incapable of continuing the vibrations which have arrived at them. This is taken advantage of in the erection of astronomical instruments, which, from the vibrations of adjacent bodies, would become so unsteady as to be perfectly useless. But if a telescope, of high magnifying power, be mounted on a clay and leaden foundation, the vibrations of surrounding bodies are stopped, and nearly cease. The same materials, with many others, equally oppose the propagation of soniferous waves; and may, therefore, to some extent, be termed non-conductors of sound. The atmosphere permits the passage of sound at the rate of about 1,140 feet per second; that is, the sonorous vibrations of any body will not be perceived by the ear in less than a second of time, if 1,140 feet of air interpose. We find, however, that water, and many solids, convey sound much more rapidly

than air; and if we make the rate of conduction in the air the standard of comparison, the following will show the relative powers of various substances:—

Air	1
Water	4
Tin	7½
Silver	9
Copper	12
Iron	17
Glass	17
Various kinds of woods, 11 to	17

Most of our readers must have noticed, in daily experience, how differently bodies conduct sound. Thus, if a long row of iron railings be struck at one extremity, the sound produced is heard at the other end long before it would be conveyed by the atmosphere.

Before we proceed further, the attention of the reader must be called to the analogy which subsists between the conduction of sound and that of electricity, but it is analogy alone. In previous pages, in the present volume, we have given, in connection with telegraph matters, a table of conductors of electricity in the shape of wires. It will there be found that while, for all ordinary purposes, copper answers best, still that all the metals differ in their conducting power in relation to electricity. Similarly we find that the same law holds good in another form in regard to sound.

In observing and stating the speed of the conduction of sound, it must be remembered that the temperature and density of any medium have the effect of modifying its conducting power; and this is most readily observed in the atmosphere. The rate, however, which we have mentioned, is pretty nearly uniform for all ordinary atmospheric changes; and, for this reason, the conduction of sound may be employed as a means of measuring distances. This depends on the fact that light travels infinitely faster than sound, requiring, as it does, no more than one second of time for traversing a distance of nearly 200,000 miles. To illustrate this mode of ascertaining distances, we will suppose a flash of lightning to be seen, and that twelve seconds elapse before the sound of thunder is heard. Presuming 1,140 feet per second to represent the rate at which the atmosphere conveys sonorous waves, we shall ascertain the distance of the place at which the flash occurred by multiplying 1,140 by 12. Thus—1,140 (the rate of sound) multiplied by 12, gives the number of feet (13,680) as the distance of the flash; and this sum, divided by 5,280 (the number of feet in a mile), shows that the position of the electric discharge must be two miles and 1,040 yards from the observer. In a similar manner, the firing of a gun at sea may indicate the distance of any vessel from the shore.

It may here be noticed that the temperature of metallic bodies and most liquid greatly affects their conducting power in relation to electricity, as already pointed out in preceding pages, and further a great heat, or excessively low temperature, may entirely remove all traces of magnetism from a previously magnetised body, such as steel, nickel, and cobalt.

If the atmosphere be greatly rarefied, or gases of less specific gravity are employed in experiments with sound, then the resulting effects are greatly modified. Thus, if a person breathe pure hydrogen, or if that gas be blown through an organ-tube, then the sound produced will lose its volume, and a shrill whistle will be noticed. We may here state, by way of anticipating our future remarks, the differences which exist in sounds. Some are sharp or acute; others dull or grave; high or low, etc.; and these differences are partly due to the source of vibration, the body vibrated, and the media through which the vibrations are propagated. It matters not, however, what pitch or intensity sound has in respect to its speed, as each kind travels at the same rate. The conducting power of any material may be readily illustrated by means of the following plan:—Place a musical box inside of a larger box covered with baize, or any woollen material, so as to prevent the passage of sound from its inside. A hole should be

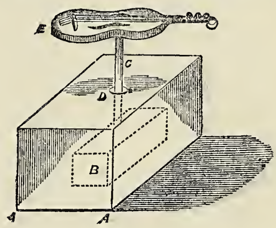


Fig. 298.

bored in the top. Into this insert a wooden rod, so that it may rest on the musical box. If a violin, or empty box of any kind, be then placed on the outer end of the wooden rod, the sounds produced by the box will be distinctly heard. On removing the violin from the rod, the sound apparently ceases. This is owing to the wood conveying sonorous vibrations from the musical box, and the subsequent diffusion of them through the air by means of the violin. The mode of carrying out this interesting experiment is illustrated in the above engraving. A A is the outer deal box, enclosing B, the musical box; C is a deal rod, through the hole D, resting on the musical box; E is a violin for diffusing sound.

This experiment also illustrates the use of sounding-boards, as seen in the piano, harp, violin, etc.; for it is not only essential that sound be conducted by a sufficient material, but also that an adequate diffuser be also present. In an analogous manner the microphone (to be afterwards described) acts as a diffuser, and increases the volume of sound conveyed by the telephone.

The stethoscope is constructed so as to convey the sounds of the beating of the heart, etc., to the ear of the person employing it; and a very common plan of ascertaining the regular supply of steam to each end of the cylinder of

a steam-engine, is that of placing a wooden rod against the cylinder—biting it with the teeth, and closing the ears. The vibrations are thus conveyed to the ear by means of the conducting-rod. If a musical box be placed at a considerable distance from the ear, so that its tones can scarcely be heard, and afterwards a deal rod be placed with one end on the box and the other between the teeth, the sounds previously inaudible will be readily perceived through the conducting power of the wood. In a similar manner, a poker, if hung by means of a piece of string held by the teeth, will produce a powerful sound when struck by a hammer or other body.

We next come to an application of the laws of the conduction of sound-vibrations which evidently was an anticipation of the electric telephone of our day. But here we must emphatically state that Professor Wheatstone, at the time of the construction of the instrument about to be described, had not the slightest idea of the instrument that by means of electricity is now used for the conduction of sound as the telephone. Being in almost daily conversation with him on the subject, his only view was to make the mechanical conduction of the deal rod as perfect as possible. We therefore repeat that the instrument now to be described was simply an anticipation on mechanical grounds of the present electrical telephone.

It was in 1855 or 1856 that this very ingenious application of the principles already enunciated was made by Professor Wheatstone, then of King's College, London. He conceived the idea of conveying musical sounds from any instrument into a distant apartment; so that a "supply" of music might readily be laid on in each room of a house, if rods were attached to any instrument and fitted with diffusers, such as we have illustrated in the last engraving. The plan was practically carried out at the London Polytechnic. In the basement of the building, a pianoforte, cornet, and violin were played; and from each a deal rod was carried, to a height of forty feet, into the upper lecture theatre. On each deal rod a harp was placed; and by these means the sound produced by each instrument was at once diffused. The effect was singular and interesting, for each instrument was distinctly heard by itself, or in concert with the rest; the music, however, all proceeding from the sound-diffusing harps. In a similar manner the sound of human voices was also conveyed, the singers being placed with their mouths close to the sounding-board of the piano in the basement, and the harp answering as the diffuser in the lecture theatre. The annexed engraving shows how the same plan may be carried out in any two apartments in the same house.

Fig. 299.—The Wheatstone Telephonic Concert.

The pianoforte and the performer are to be placed in a lower apartment, and the audience and diffusing harp in the upper one. A deal rod rests on the sounding-board of the piano, near C treble; and the harp rests on its upper extremity. So long as this arrangement is maintained the performance is distinctly heard; but if the harp in the upper apartment be removed from the deal rod, the sound instantly ceases. A violin or empty deal box answers just as well as the harp for diffusing the sound in the upper apartment.

As the improvement of the early details of this experiment were left in the hands of the editor of this work, who also suggested and carried out the arrangements, by which the human voice, or a quartet of voices, could be conveyed to another apartment, as in the case of the pianoforte and other musical instruments already referred to and illustrated, the following remarks on the precautions that had to be taken may be of interest, as bearing, in some respects, on the practical use of the electrical telephone of the present time.

Of course, the height of the building required that the deal rods should be made in separate lengths. They were chosen free from knots, cracks, etc., and were baked in an oven until they were quite dry. Only those which had stood completely this operation were used. They were then carefully planed to a thickness of about five-eighths of an inch. They were fitted together by cutting the edge of each into a cone which should exactly fit the rod to which it had to be attached, and their close adhesion was secured by brass pins driven through the wood,

and strengthened externally by a kind of brass band that passed entirely round the joint. No glue or other cement was used. The annexed cut illustrates one of these joints. One end was firmly fixed on the sounding-board of the piano, when the sound of that instrument was sent up. In the case of the cornet, the large aperture was brought as near as possible to the rod without touching it, and the case of the violin was gently pressed against the rod while being played.

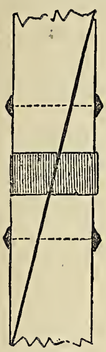


Fig. 300.

Great difficulty was at first found in conveying the human voice. However, it struck our mind that if each singer was caused to bend and sing over that portion of the piano in the basement, the length of the wires of which corresponded in producing the voice of the singer, the effect desired might be produced. This succeeded admirably. A bass singer sang over the bass-wires, tenor over the tenor wires, etc. ; and thus an excellent quartet was heard in the lecture-room through transmission of the sound by the rods from the basement.

The reason that causes us to mention these particulars will be more apparent as we proceed. But for the purpose of giving an illustration of what we mean to our readers, we instance the following as equally applicable to the mechanical telephone of Wheatstone and the electrical telephone now in use. In sounding on the piano, the first line below the treble, viz., C, the wire struck must vibrate 240 times per second, to conduct this sound by the air that must vibrate 240 times, and the drum of the ear must similarly vibrate 240 times to receive the sound. To conduct the sound by electricity, as in the telephone, the wires must convey from the transmitting to the receiving instrument also 240 vibrations of some kind or other. Thus it will be plainly perceived what is the principle on which the electrical telephone is constructed, and how far it differs from Wheatstone's arrangement.

This leads us to next consider—

Musical Sounds.

One of the most interesting, although not useful purposes to which the telephone has been applied, is that of conveying musical sounds to a distance. At the Paris Electrical Exhibition of 1881, the music and the voices of the singers were thus conveyed to a great distance (we believe about a mile) from the Grand Opéra, to a hall in the Exhibition itself, and great curiosity was shown by the visitors to hear operatic music so singularly repeated. The philosophy of the method is very simple, and depends on the laws of vibration already explained ; in fact, this curious effect well illustrates those laws, together with others relating to the conduction of sound.

We shall divide this portion of our subject into two parts. The first will deal with musical sounds as produced by instruments, and this will be followed by a brief account of the physiology of animal voice. It has already been remarked, that all sounds are caused by vibrations, but that such differ according to the body from which they proceed. Besides, the sounds so produced vary from each other in tone, and other particulars, according to certain definite laws, which will now be inquired into.

If a piece of steel be tightly held at one extremity, and then struck, it will, of course, vibrate, and, in so doing, will produce sound. If the length of the steel beyond the part at which it is held be decreased, then such sounds will become sharper. On the other hand, if the length be increased, then the sounds produced are duller, and deeper in tone. A very convenient way of trying this experiment is represented in the annexed engraving, in which *a* is an ordinary vice ; *b* a piece of well-tempered steel ribbon ; and *c c* are dotted lines, showing the vibrations produced on the steel. The steel extremity, beyond the top of the vice, can be lengthened or shortened, by passing it, more or less, through its sides or cheeks, as may be required for altering the sound.

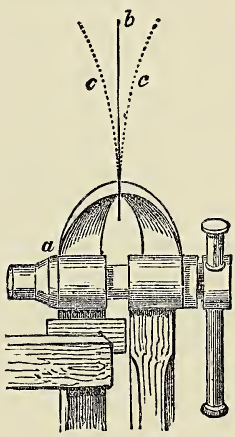


Fig. 301.

In trying this experiment, the reader may, by a little care, produce not only an apparently extensive range of sounds, but in so doing will notice that at certain intervals the same kind of sound is reproduced, but either sharper or lower, according as the length of the steel is decreased or increased. Now, these similar notes, or sounds, are termed octaves ; that is, a musical sound repeats itself at every eighth set of vibrations, when such are produced according to certain rules. But intermediate to the notes forming the extremities of the octave there are others which, to some extent, harmonise with them : such are termed thirds and fifths, owing to their relative position with that of the first or last octave note. This may readily be tried on a pianoforte, by placing the fingers on two suc-

cessive C's, and then striking the intermediate E and G. If the four notes be then struck together, the effect of their harmony will be at once apparent.

Another mode of trying the effect of increasing or lengthening a vibrating cord, is that of stretching tightly a piece of catgut between any two points. If this be vibrated, it will produce sound, as usual. If it be halved in its vibrating length, by placing the finger on it and pressing it down, midway between its two extremities, then a shriller note will be produced, which will be an octave higher than that afforded by the long cord. If, again, a piece of steel be pressed against a rapidly revolving tooth-wheel, a certain sound will be produced; but if the tooth-wheel be made to revolve twice as fast, then the previous sound will be raised an octave.

From these experiments we learn that the tone of any sound—that is, its shrillness or dulness—depends on the number of vibrations produced in any similar period of time; and that these, again, depend on the length of the vibrating body—the number of vibrations being inversely as the length of the vibrating body. This will be more easily understood if our readers will notice the length of the different strings in a harp or pianoforte. It will be found that those which produce shrill sounds are invariably the shortest; and the deeper the sound, the longer the string which produces the vibration. Violin players are thus enabled to obtain any variety of the sounds of other musical instruments, by means of the rapid movement of their fingers over the strings; for they are enabled to alter their lengths, so far as the production of sound is concerned.

We shall confine our illustration of these principles to the eight notes in the treble clef forming an octave—from C below the lines, to C on the third space, as represented below. To each of the notes we have appended their names, for the assistance of those of our readers who do not understand music. When, however, an instrument, especially a pianoforte or harp, can be had access to, such will materially aid in making our remarks understood.

English names ...	C	D	E	F	G	A	B	C
Italian do.	do	re	mi	fa	sol	la	si	do

Fig. 302.—Treble Octave.

Now, the sounds of each of these letters, in Fig. 302, are produced by a definite number of vibrations, and the length of each string. Thus, that affording C vibrates 240 times per second; whilst the upper, or octave C will vibrate 480 times per second. The length of the string producing the low C may be 45 inches; whilst that producing the upper C will be but $22\frac{1}{2}$ inches. Each of the other notes will proceed from an intermediate length of string and number of vibrations. The following table gives the value of each of these—commencing with the lower C. Some consider that 256 vibrations equal C. We have chosen the lower number, for the purpose of avoiding fractions; but the reader can easily calculate a table on that standard by using the table, or ratio, which follows this.

Name of note.	Length of cord in inches.	Number of vibrations per second.
C	45	240
D	40	270
E	36	300
F	$33\frac{3}{4}$	320
G	30	360
A	27	400
B	24	450
C	$22\frac{1}{2}$	480

The law of the relation existing between the number of vibrations, the length of the cord, and the nature of the sounds produced, is thus at once made evident. The ratio existing between each of these is shown in the following table—commencing with low C, as before, it being the standard.

Name of note . .	C	D	E	F	G	A	B	C
Ratio of the length of the cord . .	1	$\frac{8}{9}$	$\frac{4}{5}$	$\frac{3}{4}$	$\frac{2}{3}$	$\frac{3}{5}$	$\frac{8}{15}$	$\frac{1}{2}$
Ratio of vibrations	1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2

From which we perceive, as before stated, that the length of the cord is inversely as the number of vibrations, and *vice versâ*. We have already observed that harmonies are afforded when certain sounds are produced together. This occurs when C and G (below), which are five notes apart, C and E (above), which are three notes apart, and C, E, and G, are struck together—forming, as they do, a chord in which thirds and fifths are combined. The effects of such combinations are naturally pleasing to the ear; but this is not a pure matter of taste only, for if some pieces of paper are allowed to fall on strings thus vibrating, they will arrange themselves in such positions as will accord with those of the length of the octave, the third and fifth, pointed out in our last table.

We have confined these remarks to stringed instruments only; but they are equally applicable to those in which wind is alone employed. Thus, in the organ, the length of the pipes corresponds to the length of the string in the pianoforte, because they enclose a similar length of air; and it is the vibration of this which causes the sound of different notes. In the flute, cornopean, etc., the length of the column of air is regulated by the skill of the performer; hence the difficulty experienced in acquiring the art of blowing those instruments properly. Many instruments, of entirely different kind of construction, such as the harmonium, concertina, the pan-pipes, bells, etc., all owe the production of their various notes to the laws we have here explained.

The diffusion of sound, from an instrument producing it, is effected by means of a readily vibrating body. Of such kind is the sounding-board of the piano, harp, violin, etc. We have already mentioned various facts relating to this subject, and must therefore refer our readers to our previous remarks. Great variety exists in the power, sweetness, and other qualities of instruments. Thus the flute and the cornopean, although each producing their sounds directly by the vibration of the air, convey entirely different effects to the ear. The same may be said of the violin and harp, amongst stringed instruments. These results chiefly arise from the nature and quality of the material employed, and the skill exhibited in their construction. A fastidious, or rather educated musical ear, can detect small differences in this respect; and even to persons with no special musical taste, it is by no means difficult to distinguish the tone of the same kind of instruments made by different manufacturers. It is, however, no part of our plan to enter into such details, our object being solely to illustrate the principles of which we have been speaking.

We next turn to inquire into the production of animal sounds, confining our attention, however, to the cause of voice in man, and its conduction through the air or other suitable medium for conveying the vibrations.

The organs concerned in voice and speech may be described as the chest and lungs, the windpipe, the larynx, the posterior cavity of the mouth, the nostrils, which communicate with that posterior cavity, the palate, the tongue, the teeth, and the lips. The sounds which constitute voice belong to the order of musical sounds, independently altogether of the singing voice. All that is rightly termed voice, takes place in the larynx, which is properly the instrument of voice. But even independently of the modifications by which voice is changed into articulate speech, the voice is variously affected by the other parts which have been enumerated: by the chest, as regulating the force of the air; by the windpipe, as susceptible of several degrees of length and tension; by the posterior cavity of the mouth, as offering an expanded vault; by the nostril, as affording a double passage of exit for the breath; and by the various conditions of the tongue, the palate, the teeth, the lips, according to the position they happen to be in at the moment.

To attempt to explain here all the different muscles, etc., which tend to the production of the human voice would lead far into the subject of anatomy, and would be foreign to our purpose. Our object is to show that as in the production of sound by other means, so the voice depends on the vibrations produced by our volition. It is by the vocal ligaments, which are composed of elastic tissue, that this result takes place. In the investigation of the cause of the human voice two points in particular deserve attention: first, the precise seat of the sound; and secondly, the mode in which these sounds are produced.

As to the first question, it is now determined, beyond all doubt, that the sound of the voice is generated in the glottis, and neither above nor below that point. Before going further, it should be remarked that this word "glottis" has not always been used in exactly the same sense. "By turns," says the eminent French physiologist, Adelon, "the superior aperture of the larynx, its inferior aperture, and the intermediate space between these two apertures, have borne the name of glottis; but, according to the etymology of the word, derived from γλοσσα—the tongue, the speech—no other part of the larynx should be called by that name but that where the vocal sound is formed; and we shall see that that part is the inferior aperture or chink." In this sense alone, then, the word glottis is here employed—namely, to signify the aperture between the two vocal ligaments; that is, between the two inferior vocal cords, as they are sometimes called.

It has been already remarked that the vocal ligaments are composed of elastic tissue; and it is owing to this elasticity that they are adapted to the office which they perform. While, then, it is quite certain that no proper vocal sounds can be produced except in the glottis, it seems manifest that the adjacent and somewhat abundant tissue of the same kind is susceptible of a vibration and resonance in unison, so as at least to modify the sounds of the voice.

In reference to the second question—what is the nature of the change produced in the glottis during the formation of voice?—no inconsiderable difficulty is met with. The points of debate which have arisen on this subject are, whether the vocal ligaments be a set of membranous cords obeying the laws of musical strings; if the aperture of the glottis be a reeded instrument, in which the vocal ligaments play the part of vibrating tongues; or even whether the real source of the sounds of the voice be not a molecular vibration of the air, produced by its passage through the narrow aperture of the glottis; and, lastly, whether the organ of the voice does not, in part, combine all these three sources of sound, so as to be at once, in some respects, a stringed instrument, a tongued instrument, and a simple wind instrument. The prevailing opinion of the present day is that the larynx is a wind instrument, but a reeded one.

It has been hinted that the vocal ligaments may possibly act not only as vibrating tongues in the production of voice, but also on the principle of musical strings. On this point a few words must be added. It may seem, at first sight, that the remark of so distinguished a philosopher as Biot, when he says, "What is there in the larynx that resembles a vibrating string? Where is the space for such a string of sufficient length to yield the lower notes of the voice? How could sounds, of the compass which the human voice represents, be produced by a string which the larynx would contain?"—would suffice altogether to set aside the idea of the vocal cords acting as musical strings. But Biot here seems to have fallen into error. Deep notes are still produced by a string greatly shortened, if it retain, after a sufficient amount

of relaxation, the elasticity required for vibration. His attention does not seem to have been drawn sufficiently to the nature of organic membranes; strips of india-rubber, and elastic animal membranes, still retaining enough of elasticity for this purpose, after being much relaxed. There is, therefore, a perfect agreement between the vocal cords and vibrating strings, though their vibrations, whether as strings or as tongues, are produced not by the direct impulse of a solid body, but by the momentum of air. When the ordinary principles to which musical strings are subject are applied to the vocal ligaments, there is found to be a very close agreement, if allowance be made for the peculiarities of animal substances, as respects their elasticity and the like.

We have thus far shown how ordinary sound, musical sounds, and the human voice all depend on vibrations for their production, and how, therefore, the telephone may be expected and employed to convey those vibrations to a distance. There is one subject, however, that requires attention, especially in regard to the working of the telephone: it is the interference of other vibrations with those that the telephone alone should convey. It will subsequently be seen that the wires conveying messages by the electrical telephone occasionally, when side by side, produce some curious and occasionally amusing results. These annoyances may in part be explained by a few remarks on "Interference" in relation to sound-producing vibrations.

This subject is amply illustrated in the case of the interference of light. When two waves of that force are in certain positions or phases, and in motion, they combine and destroy each other. The waves on the sea-shore frequently show the same phenomena if carefully watched, which is especially to be noticed when the ripples cross each other on the shore on a calm day. In like manner the waves of sound act on each other, as may be proved by the following simple experiment.

Place a glass cylinder on a table, and having struck a tuning-fork, hold it over the rim of the vessel, when that will at once vibrate, and produce a sound identical with that of the fork. Then bring another glass vessel, held horizontally near the first, in the manner represented in the following figure, when the sound will instantly cease.

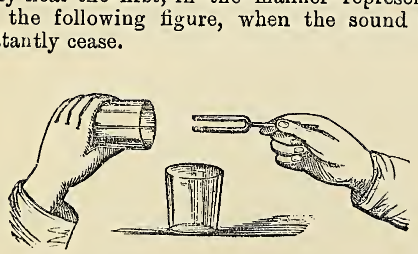


Fig. 303.—Interference of Sound.

The result of the destruction of sound arises solely from the interference of two waves, which neutralise each other. In a similar manner, the same effect is produced in a building when two or more waves of sound act on each other after reflection, or by a reflected wave interfering with one transmitted directly from the speaker. For this reason there are many places in our public buildings in which it is impossible to distinguish the different words spoken. They are intermingled with each other, and so mutually destroy their intended effect. The practical application of this law as operating on the working of the telephone, will be more fully understood when the difficulties that occasionally arise are described at a future page.

Having thus dealt with what may be called the fundamental principles of the production of sound and its transmission by ordinary conductors, we proceed to describe the electrical telephone as now used. Its early history is thus sketched in *Engineering*, to the proprietors of which we are indebted for some of the following illustrations:—

In the year 1860, Philipp Reis, of Friedrichsdorf, near Homburg, following the researches of Wertheim, Marian, and Henry, upon the production of sounds by electricity, invented the telephone which bears his name, and which may be seen at South Kensington. The telephone of Reis is of two parts: a transmitting instrument and a receiver. The former consists essentially of a stretched membrane which, by vibrating in unison with the impulses it receives from musical sounds played near it, transforms those impulses into a series of electrical currents by a simple make-and-break arrangement, and these currents acting on the receiving instrument, which may be hundreds of miles distant, reproduce the corresponding notes, so that a tune played at one station can be distinctly heard at the other.

The receiving instrument is founded upon the well-known phenomenon discovered by Page in the year 1837, that a distinct sound accompanies the demagnetisation of an iron bar placed in an electro-magnetic helix. It consists of a soft iron bar about the size of a knitting needle, surrounded by a helix of wire which forms part of a voltaic circuit with the transmitting instrument, and for intensifying the effect both instruments are provided with sounding-boards or resonators. From the above description it will be seen that if a note which makes, say, one hundred vibrations per second, be sounded in the neighbourhood of the transmitting instrument, its membrane will make one hundred corresponding vibrations, making and breaking the voltaic current one hundred times, and producing one hundred demagnetisations in the receiving instrument for every second of time, so that exactly the same note that was sounded in the transmitter will be audible at the distant station. It is obvious that the duration of, and time between two notes must be identical at both ends of the conducting wire, and thus is reproduced automatically and without a possibility of error the elements which make up melody, viz., correctness of note combined with measure of time.

Following Reis in Germany, Elisha Gray, in

America, constructed, in 1874, his far more perfect electric telephone, in which the transmitting instrument consists of a vibrating reed, which is at once a note producer and a rheotome or contact breaker. It is tuned like the reed of a harmonium to its proper note, and when adjusted can only transmit to the receiving instrument the number of currents per second corresponding to the vibrations producing its note. Elisha Gray's receiving instrument is electrically similar in principle to that of Reis, but consists of a horseshoe electro-magnet mounted upon a wooden sounding box or resonator with a heavy armature attached to its poles. The transmitting instrument is provided with a key-board similar to that of a harmonium, and each note has its corresponding key and vibrating reed.

The same inventor has since introduced his splendidly worked out telephonic telegraph, by which four or more distinct messages may be transmitted in the Morse code simultaneously along a single wire. This apparatus depends for its principle upon having a vibrator at the receiving station, tuned so as to be affected only by its corresponding transmitter at the sending station, and thus the receiving instruments along a line of wire have the power of selecting those messages intended for themselves, and letting all others pass. This has also been accomplished by a Danish engineer, M. Paul La Cour, who employs vibratory tuning-forks for transmitting the impulses, and a series of corresponding tuning-forks, each arm of which is enclosed in a magnetic helix for the selecting instrument. This selecting instrument can be used either as a receiving telephone; or by being employed as an intermediate relay, may transmit the signals to ordinary telegraph instruments.

We give illustrations of the transmitting and receiving instruments of Mr. Graham Bell's articulating telephone, by which the sound of the human voice may be transmitted by electricity along a telegraph line, and heard, as a voice, at the other end.

The articulating telephone of Mr. Graham Bell, like those of Reis and Gray, consists of two parts—a transmitting instrument and a receiver—and one cannot but be struck at the extreme simplicity of both instruments: so simple indeed that were it not for the high authority of Sir William Thomson, one might be pardoned at entertaining some doubts of their capability of producing such marvellous results.

The transmitting instrument, which is represented in Fig. 304, consists of a horizontal electro-magnet attached to a pillar about two inches above a horizontal mahogany stand; in front of the poles of this magnet—or more correctly speaking magneto-electric inductor—is fixed to the stand in a vertical plane a circular brass ring, over which is stretched a membrane, carrying at its centre a small oblong piece of soft iron which plays in front of the inductor magnet whenever the membrane is in a state of vibration. This membrane can be tightened like a drum by the three mill-headed screws shown in the drawing. The ends of the coil surrounding the magnet terminate in two binding screws by which the instrument is put in circuit with the receiving instrument, which is shown in Fig. 305. This instrument is nothing more than one of the tubular electro-magnets invented by M. Niclès in the year 1852, but which has been re-invented under various fancy names several times since. It consists of a vertical bar electro-magnet enclosed in a tube of soft iron, by which its magnetic field is condensed and its attractive power within that area increased. Over this is fixed, attached by a screw at a point near its circumference, a thin sheet iron armature of the thickness of a sheet of cartridge paper, and this when under the influence of the transmitted currents acts partly as a vibrator and partly as a resonator. The magnet with its armature is mounted upon a little bridge which is attached to a mahogany stand similar to that of the transmitting instrument.

The action of the apparatus is as follows: When a note or a word is sounded into the mouthpiece of the transmitter, its membrane vibrates in unison with the sound, and in doing so carries the soft iron inductor attached to it backwards and forwards in presence of the electro-magnet, inducing a series of magneto-electric currents in its surrounding helix, which are transmitted by the conducting wire to the receiving instrument, and a corresponding vibration is therefore set up in the thin iron amature sufficient to produce sonorous vibrations by which articulated words can be distinctly and clearly recognised.

In all previous attempts at producing this result, the vibrations were produced by a make-and-break arrangement, so that while the number of vibrations per second as well as the time measures were correctly transmitted, there was no variation in the strength of the current, whereby the quality of tone was also recorded. This defect did not prevent the transmission of pure musical notes, nor even the discord produced by a mixture of them, but the complicated variations of tone, of quality, and of modulation which make up the human voice, required something more than a mere isochronism of vibratory impulses.

In Mr. Bell's apparatus not only are the vibrations in the receiving instrument isochronous with those of the transmitting membrane, but they are at the same time similar in quality to the sound producing them, for the currents being induced by an inductor vibrating with the voice, differences of amplitude of vibrations cause differences in strength of the impulses, and the articulate sound as of a person speaking is produced at the other end.

Of the capabilities of this very beautiful invention we cannot give them better than in the words of an ear witness, and no less an authority than Sir William Thomson, who in his opening address to Section A at the British Association at Glasgow, thus referred to it:—

"In the Canadian Department I heard 'To be or not to be . . . . there's the rub,' through an electric telegraph wire; but scorning monosyllables, the electric articulation rose to higher flights, and gave me passages taken at ran-

dom from the New York newspapers: 'S. S. Cox has arrived' (I failed to make out the 'S. S. Cox'); 'the City of New York;' 'Senator Morton;' 'the Senate has resolved to print a thousand extra copies;' 'the Americans in London have resolved to celebrate the coming 4th of July.' All this my own ears heard, spoken to me with unmistakable distinctness by the then circular disc armature of just such another little electro-magnet as this which I hold in my hand. The words were shouted with a clear and loud voice by my colleague judge, Professor Watson, at the far end of the telegraph wire, holding his mouth close to a stretched membrane, such as you see before you here, carrying a little piece of soft iron, which was thus made to perform in the neighbourhood of an electro-magnet, in circuit with the line, invention which devised such very slight means to realise the mathematical conception that if electricity is to convey all the delicacies of quality which distinguish articulate speech, the strength of its current must vary continuously and as nearly as may be in simple proportion to the velocity of a particle of air engaged in constituting the sound."

It is almost needless to add that the principle of the actual working of the electrical telephone having been discovered, various modifications of the instrument soon appeared. The invention of the instrument in 1860 by Professor Reis, already referred to at page 606, *ante*, pointed to the transmission of musical notes by means of electricity as a probable method of telegraphing in the future. The last few years have seen the telephone amply developed, and its practical

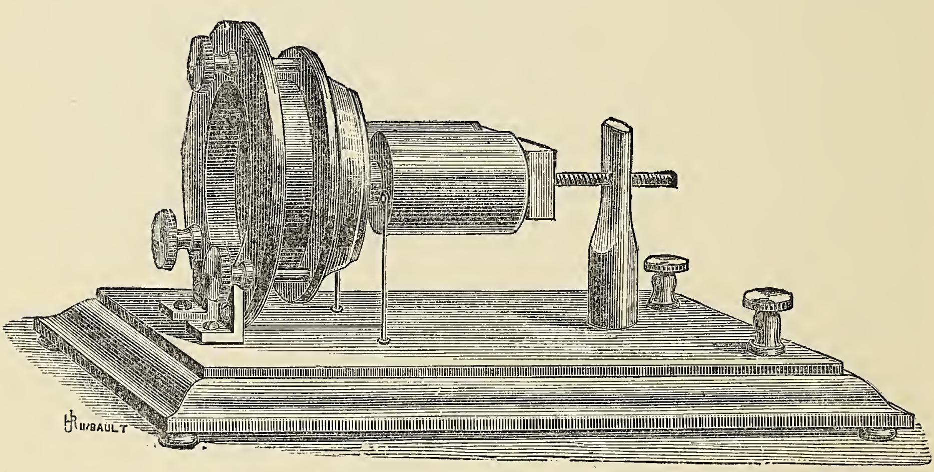


Fig. 304.—Bell's Telephone—Transmitting Instrument.

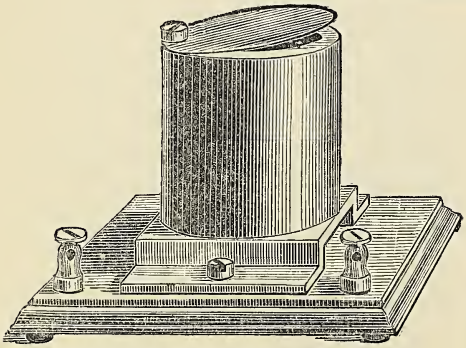


Fig. 305.—Bell's Telephone—Receiving Instrument.

motions proportional to the sonorific motions of the air. This, the greatest by far of all the marvels of the electric telegraph, is due to a young countryman of our own, Mr. Graham Bell, of Edinburgh and Montreal and Boston, now becoming a naturalised citizen of the United States. Who can but admire the hardihood of

application to telegraphy an accomplished success. The principal merit of this advance is due to Mr. Cromwell F. Varley of England, to M. Paul La Cour of Denmark, and Mr. Elisha Gray of the United States. It is not generally known that Mr. Varley deserves a considerable share of the credit of this work; but it will be seen from an examination of his patent of 1870, that he anticipated several of the ideas more recently worked out by others. But the crown of this line of invention is that of the articulating telephone of Professor Graham Bell, which we have already described at page 607, *ante*.

The first results of M. Paul La Cour's system (sub-director of the Meteorological Institution of Copenhagen) were embodied in an English patent, dated 2nd September, 1874. The current interrupter, in his sending apparatus, consisted of a tuning-fork. When this fork was put into vibration, at each oscillation it made contact with a spring which could be adjusted to the fork by a screw. Here the reader will perceive the reason of our drawing attention to the vibrations of a tuning-fork as simply illustrative of the production of sound referred to at page

599, *ante*. In M La Cour's system the intermissions of the current would of course be equal to the number of vibrations of the fork and synchronous with them. On the fork depended the number of intermissions per second. The receiving instrument consisted of a tuning-fork, not of steel, like the transmitting fork, but of soft iron with each of its legs inserted into the hollow of a bobbin of silk-covered copper wire. Two upright electro-magnets were set so that their poles were brought into close proximity with the tips of the legs of the fork which projected through the bobbins and were free to vibrate. The current coming in from the line passed through the bobbins, and thus through the electro-magnets to the earth. By this means the soft iron legs of the forks acquired opposite polarity, and being close to the poles of the electro-magnet of opposite kind to themselves were forcibly pulled out and let go in rapid succession by the intermittent current. Thus a vibration was set up in the fork which was formed to vibrate in unison with the transmitting fork.

The chief advantages of this system are that it easily admits of multiplex telegraphy or a number of distinct signals being simultaneously transmitted through one line wire; and that it allows, by means of the local circuit, of the use of certain ordinary instruments for recording the messages. The intermittent current acts only on a tuning-fork in unison with the fork which rendered it intermittent. Hence a number of forks of different note may be employed, to send by the signalling key a number of intermittent currents into the line at once; and the same number of forks in unison with these may thereby be set in vibration at the receiving station. The superimposed vibrations will not confuse each other. The fork in unison will in each case be started by its proper current, but will be still to all the rest.

By this means a combination of elementary signals representing a word can be at once telegraphed by depressing two or more signalling keys attached to two or more transmitting forks, "played off" as one plays the keys of a musical instrument. Or again, the signals simultaneously sent may each be a part of distinct messages. This means will also allow of a terminal station on a line communicating with any or several intermediate stations, or *vice versâ*, without disturbing in any way the arrangements of the other stations. A signal can thus be sent between any two stations without the other stations being aware of it. In all cases where it is important, as in times of war, or to give alarm of fire, etc., to transmit signals only to certain points, this system is applicable.

We must next briefly notice the system invented by Mr. Elisha Gray, of Chicago, and for the history of this we are indebted to the columns of *Engineering*. In 1874, a few months before, M. La Cour produced an English patent, whose invention we have already noticed, for a method of transmitting musical tones of any desired pitch (see *ante*, p. 604, in regard to musical sounds) by means of an electrical circuit, in which a series of electrical impulses, corresponding in number to the number of vibrations of the tone were caused to pass. The succession of currents could be created by the use of an induction coil, in which a current in the primary coil, interrupted by a vibrating electrotome or contact-breaker, would set up a series of high potential in the secondary coil. These induced impulses would be caused to traverse the line, and give out a note corresponding to their rate of succession by actuating a coil of wire enclosing a core of soft iron, as in Varley's system, or by passing through living tissue in contact with any resonant body. Apart from the details of the mechanism, this last was the especial part of this patent. It means that if a person places himself in the secondary circuit, and brings his hand or any other portion of his body in contact with any resonant conductor of electricity, so that the circuit is completed through it, and the impulses flow from the flesh to the body, these impulses will produce a corresponding number of vibrations in the body, and if of sufficient rate and intensity, a musical note will be the result, of a quality depending on the nature of the resonant substance, but of the same pitch as that produced by the vibrations of the vibrating circuit-breaker at the sending end. The resonant body may be a thin metallic cylinder, or a plate of metal stretched above the box of a violin by metallic strings, a sheet of paper-foil stretched over a metal ring, or other similar contrivances. (See our remarks on Wheatstone's telephonic arrangements, etc., at page 601, *ante*, where this question is a subject of discussion and illustration.)

But Mr. Gray's early patents made no mention of multiplex telegraphy. He proposed, in applying his invention to telegraphy, to supersede the Morse alphabet of single signals in a certain order for each letter by employing tones of different pitch for the letters. These tones could be produced more rapidly in succession than printed or impressed marks, and their duration would be shorter than the time now required to make them. If the Morse code were still used, dots could be represented by one tone and dashes by another. But, discarding the Morse code, signals could be produced by various combinations of elementary tones which could soon be understood by the operator, who, distinguishing them by his ear, would have his eyes and hands free to write the message down.

In subsequent English patents, however (No. 974 of 1875 and No. 1,874 of 1876), Mr. Gray describes the application of his telephone to multiplex telegraphy, and the use of the ordinary Morse receiving instrument actuated by a local battery in conjunction with it. It would, however, be foreign to our purpose to enter into details of the mechanical parts of these inventions. In 1877 Mr. Gray's invention was successfully operated on the lines of the Western Union Telegraph Company from Boston to New York, and other places—distances of several hundred miles—and it was stated that as many as four messages had been successfully transmitted simultaneously with it over 2,400 miles of that Company's lines.

As might be expected, the value of telephonic

telegraphy became rapidly recognised and developed, and great improvements were made which rendered it more useful for commercial and general purposes. In 1879 an improved form of Bell's Telephone was invented. Among the most important of the improvements was the compound nature of the magnet, which is composed of four bars of steel of flat rectangular section placed in two pairs, which are separated by a similar bar of soft wood, and united at their upper extremity to a soft iron pole-piece, which is surrounded by the coil of insulated wire which is in circuit with the distant station. The case is constructed of ebonite, and is remarkable for its high-class workmanship and finish, and the mouthpiece screws down over the body of the instrument so as firmly to hold the edge of the ferrotype diaphragm between itself and the rest of the case; by this means holding-down screws are dispensed with, and the instrument is rendered not only more sightly but simpler and more readily adjustable.

The working of the instrument is everything that could be desired, and its clearness of articulation is very remarkable. The instrument in this form was rapidly introduced by the Telephone Company, and it is an interesting fact that Sir Garnet Wolseley took out no less than fifty pairs of these instruments for use in the campaign in Zululand in 1879.

As usual, there were numerous claimants for the honour of being the first inventors of the telephone, especially in regard to the United States. Much acrimony of feeling existed, but eventually the question was legally decided by one of the United States Courts in terms that left no doubt as to the originality of Mr. Bell's invention. On this point we quote the following from the columns of *Engineering*, page 315, No. 821, Vol. XXXII., dated September 23, 1881, by which the claims of our countryman are fully and legally established, at least so far as claimants of the United States of America are concerned:—

"The American press has long ignored the legitimate claims of Professor Graham Bell to be accounted the first and true inventor of the speaking telephone. That gentleman had the misfortune to be born an Englishman, or speaking more strictly, a Scotchman; and the lion's share of the invention has always been accredited in the United States to native Americans, such as Mr. Edison and Mr. Elisha Gray. The recent decision of Judge Lowell, of the United States Circuit Court of Boston, Mass., has, therefore, caused considerable surprise and disappointment in America. The judge virtually declares Professor Bell the original inventor of the speaking telegraph, and confirms to the American Bell Telephone Company the exclusive right in the United States of talking over a wire by means of electricity. He says: 'If the Bell patents were for a mere arrangement or combination of old devices to produce a somewhat better result in a known art, then, no doubt, a person who substituted a new element, not known at the date of the patent, might escape the charge of infringement. But Bell discovered a new art, that of transmitting speech by electricity, and has a right to hold the broadest claim for it which can be permitted in any case—not to abstract right of sending sound by telegraph without any regard to means, but to all means and processes which he has both invented and claimed.' At first sight this decision appears at variance with that of our own judges, Baron Pollock and Mr. Fitz-James Stephen, in the trial between the British Post Office authorities and the Bell Telephone Company. They ruled that the telephone was a telegraph, and in that case we may well ask if telephoning can therefore be a new art, as the American judge defines it. The English judges were impressed by the counsel for the Post Office with the scientific evolution of the telephone, and evidently regarded the case from an internal point of view; they had been taught to see how Reis's musical telephone was related to the ordinary 'sounder,' and how Bell's telephone could be assimilated to Reis's. The American judge has, however, evidently looked at the case from an external standpoint, and decided on the difference of results effected rather than on the scientific likeness of the means employed; and we question whether his decision is not the clearest and the best. The telephoning of speech is fairly entitled to be ranked as a new art; and though Professor Bell cannot lay claim to the abstract right of sending speech, he is at liberty to claim all the means and processes covered by his patents. The decision will affect the prospects of a great many patentees who have taken out numerous patents for improvements in telephonic apparatus based on Bell's invention; and if it is confirmed by the Supreme Court of the United States, it will put a gigantic monopoly into the hands of the American Bell Telephone Company."

Reference is made above to the action of the British Government in claiming a right to telephonic communication throughout the United Kingdom as being a branch of telegraphy, and, therefore, being amenable to the law by which the right of sending messages, excepting in certain cases, by telegraph, was vested solely in the Post Office authorities by virtue of the Act that transferred the rights, properties, etc., of the old Telegraph Companies to the Government in 1870. The decision was given in favour of the Postal authorities by our judges, and had not some arrangement been made, the monopoly would have rested in the hands of the Government, to the entire destruction of private enterprise. In the preceding chapter an account has been given of the past and present of our British Telegraph system, in which this subject is mentioned; and in regard to the relation now subsisting between the Postal authorities and the then newly-formed Telephone Companies, we quote the following *verbatim* from the Postmaster General's Report for 1880-81:—

"On the 20th of December (1880) an important decision of the Exchequer Division of the High Court of Justice defining the rights of the Department in connection with Telephones was given against the companies which had established exchanges. As, however, they were

apparently, under the belief that they had infringed no law, I held myself ready to meet them with liberal terms, and, after much negotiation, concluded an agreement which, while protecting the interests of the public, afforded reasonable advantages to the companies concerned. The system of Telephonic intercommunication is, therefore, now being extended partly through the agency of Companies and partly by the Post Office. The Department has in course of completion Telephone intercommunication systems at Swansea, Glasgow, Greenock, Hull, Manchester to Liverpool, Newport to Cardiff, Leicester, Sunderland, and other towns, and is receiving applications from many quarters."

As already intimated, the use of the telephone is rapidly advancing. In most of our large towns it is commonly applied between the offices of merchants and the Central Exchange, and one of the most recent novelties has been that of fitting up a telephone by which a member of a church is enabled to hear the whole of the service at his own residence situated some distance off.

The Paris Exhibition of 1881 was prolific in illustrations of the improvements and use of the telephone, and other applications of electricity. In regard to one of the telephone applications, the following is a brief account:—

"One of the most popular attractions at the Paris Electrical Exhibition was the nightly demonstration of the marvellous powers of the Ader telephone, by its transmission of the singing on the stage and the music in the orchestra, of the Grand Opera at Paris, to a suite of four rooms reserved for the purpose in one of the galleries of the Palais de l'Industrie. This demonstration was given nightly between eight and eleven o'clock, and the enormous number of people who crowded the entrance to the building before the doors were opened to the evening visitors, rapidly resolved themselves into patient *queues* as soon as they could obtain access to the gallery adjoining the telephone rooms. There they patiently awaited their time for admission, and the privilege of hearing for a few minutes whatever might be going on at the Opera, solo, chorus, instrumental music, or possibly all three, until the allotted time had expired, and the listeners had to give way for a fresh instalment from the outside. In this way eighty telephones were constantly at work at the same time, at short intervals the communication being shifted to another set of eighty similar instruments in two other rooms. It may be remarked in passing that this distant audience of the performance at the Opera enjoyed their allotted moments of actual transmission, and that interludes did not count. Certainly nothing has ever been done before so effectually to popularise science, and to render the masses familiar with the effect, however ignorant they may be of the cause, of this marvellous invention, the first feeble voice of which was heard in the Centennial Exhibition of 1876."

But the telephone by itself is, comparatively speaking, an imperfect instrument. When we described Wheatstone's experiments and results with the mechanical telephone, at page 602, *ante*, the necessity of a diffuser of sound was pointed out. In regard to the electrical telephone, an instrument that can increase the sonorous effect of the vibrations transmitted by it is equally necessary, and for this purpose the microphone is employed. In its simplest form it consists of a stand on which two pieces of gas carbon are placed in the manner shown in the annexed engraving. *a* is a longitudinal piece of car-

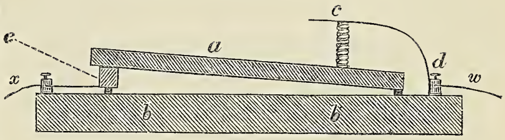


Fig. 306.

bon placed lengthways on a stand, *b b*. A spring, *c*, presses gently on *a*, and thereby connects it by the binding screw, *d*, with a wire, *w*, which brings the current from the transmitting instrument of the telephone. *e* is a piece of gas carbon placed at right angles to *a*, from which it receives the vibrations transmitted from the telephone by *w*, *d*, and *c*. From *e* proceeds a wire, *x*, which carries on the vibrations of the transmitting instrument to the receiving one. The object of the microphone is thus that of increasing the power and distinctness of sound that arrives at the receiving instrument applied to the ear of the person who listens to the message that has been sent. The microphone is an absolute necessity for messages sent through a long circuit, although the telephone would be sufficient of itself to transmit messages distinctly for short distances, say between two neighbouring houses. The microphone transmitter, in fact, enables stronger currents to be sent along the line. It thereby overcomes leakage, and the feebler induction noises which affect the telephone, and which have been in part explained in our remarks on the interferences of the waves of light and sound, at page 606, *ante*.

Ader's telephone, as used at the Paris Electrical Exhibition, has already been mentioned. We extract the following notices of two other instruments, as shown and used at the same time, from the columns of *Engineering*:—

"A remarkable sensitive transmitter, shown in operation in the Belgian Section of the Exhibition, was the 'Pantelephone,' the invention of M. Léon de Locht-Labye, Honorary Engineer of Mines at Liége. It is possible to stand some 15 or 20 yards distant from this peculiar form of microphone and transmit speech by it. Of course if the speaker is nearer to it the result is all the better. The whole arrangement is enclosed in a box which hangs against the wall like a desk, and exposes the front of the vibrating diaphragm to the impingement of the sonorous waves. The device is somewhat similar to the spring microphone con-

trived by Mr. Blake; but the hinged diaphragm appears to confer an additional sensibility. The pantelephone transmits, as we have already said, words spoken at a distance of 15 yards without raising the voice very appreciably, and the barking of a dog or the crowing of a cock some 40 yards distant is faithfully sent by it to the receiver. This remarkable acuteness of hearing, if one may use the term, is likely to be of use when the telephone comes to be more applied than it is now to the transmission of sermons, lectures, and public orations, from the audience hall."

Another form of the telephone is described as follows:—

"The most novel telephone in the Exhibition was, however, that of Professor A. E. Dolbear, of Tuft's College, Massachusetts, U.S., a gentleman who has been engaged in studying the subject of telephony for several years past. Dolbear's telephone is claimed to be less subject to induction noises than any other, partly because the currents which traverse the line are borne in the secondary wire of an induction coil, and partly because there is no complete circuit at all. Both of these remedies have been before suggested as a remedy for induction clamour. The intenser currents of the secondary coil can be more readily distinguished than the ordinary undulating currents coming straight from the microphone transmitter; while a condenser placed in circuit with the receiving telephone would, it was supposed, have the effect of breaking the circuit of the induction currents while it only sharpened, so to speak, the undulations of the vocal currents, and in so doing overcame the retardation of signals produced on long lines by the neighbourhood of the earth. Now Dolbear's receiver is itself an air condenser, and hence it is believed to combine the two properties of suppressing the induction noises and improving the articulation on long lines by correcting to some extent the retardation of currents due to the static induction of the ground. Whether this is really the case experiment will verify; but we understand that the results of recent trials on a line from London to Norwich, a distance of 126 miles, were highly satisfactory. The elimination of induction clamour was very marked, and the speech was quite distinct. This cannot be called a long line as far as retardation is concerned, but the main drawback to be overcome in telephony is the induction disturbances, and Dolbear's instrument appears to be specially adapted for that purpose."

We have devoted much space to describing the new art of electrical telephony because it promises to become shortly an effective, if not an almost general substitute for the ordinary mode of telegraphing by signals, already so fully described in the preceding pages. We now pass on to consider an important improvement on the old system, in the form of—

Duplex Telegraphy.

The duplex system of working telegraph lines is the most important and promising advance made in electric telegraphy. In order the better to understand the duplex system it may be best to consider first the connections necessary for the ordinary method of working a telegraphic circuit, or, as it is now called, for simplex telegraphy. Fig. 307 (1) represents these connections.

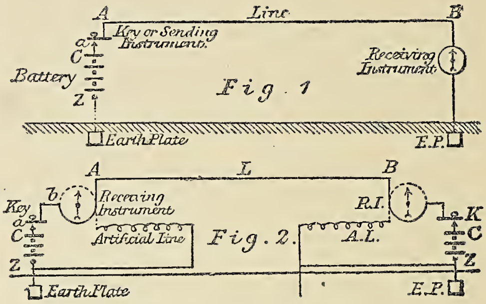


Fig. 307.—Duplex Telegraphy.

A B is the line between the sending station (or station from which the message is sent) A, and the receiving station (or station at which the message is received) B. At station A, C Z is the battery made up of a series of voltaic cells, one pole of which, say the copper pole, is connected to the key or sending instrument. The other pole of the battery is connected to a plate, usually of copper, buried deep in the earth and called the earth plate. The lever of the key is connected to the line wire. At station B the line is joined to the receiving instrument, which may be the Morse, the needle instrument, or any other, and through the receiving instrument to the earth plate there. When the handle of the key at station A is depressed into contact at *a*, the current flows from the copper plate of the battery into the line, along the line through the receiving instrument at station B to the earth, and, in effect at least, back through the earth to the zinc pole of the battery, thus completing its circuit. As it passes through the receiving instrument it makes its signal, and as often as the current is let into the line at station A so is a signal made at B. On land lines it is even made at nearly the same instant of time. No sensible difference of time between sending at station A and receiving at station B is detected even on very long land lines. But, as is well known, it is different in submarine cables. In a land line the current is confined on the iron wire, in other words, is kept from escaping to earth by the air surrounding it and the porcelain or other insulators which fix it to the poles. In a submarine or subterranean line the current is confined on the copper wire by a coating of gutta-percha or india-rubber. But in the case of a land line the earth is far removed from the wire, and consequently its inductive action on the current is almost inappreciable, whereas in the case of a submarine line the earth or water (which is the same thing as far as induction is concerned) closely surrounds the

wire and exercises a curious retarding effect, due to induction, on the current traversing it. The electricity is, as it were, held back in its passage along the wire by the mutual attraction between itself and the electricity which it *induces* in the circumjacent earth, and the current takes a distinct time to flow from the sending end of the cable to the receiving end. Moreover, the nature of its flow is changed. Instead of rushing along full strength, like a bullet, so to speak, as it does on a land line, the current flows like an undulation or wave. For some time after the battery is put on at the sending end no effect is noticed on long lines by the most delicate receiving instruments at the other end; then a very slight effect is noticeable, which gradually increases till it attains its maximum, and finally dies away as slowly as it came. This retardation materially diminishes the speed of working through long submarine cables, and renders instruments of special delicacy necessary to commercial success in ocean telegraphy. Of this kind and one of the most delicate is Thomson's siphon recorder, already noticed as now largely used for submarine telegraphy.

We come now to that somewhat abstruse and incomprehensible system of telegraphy called the duplex system, but which might perhaps have been better named the counter system. It may be defined as the sending of a message from both ends of a line at once, or the sending and receiving of messages at either end simultaneously. It is popularly believed that the two messages which are thus communicated through the cable in opposite directions at once, pass each other on the way in some mysterious fashion, but such is not the case. Duplex telegraphy has been practically solved by ingeniously connecting up the ordinary instruments so that the signalling currents from the opposite ends of the line shall *oppose* each other or not as the case may be, and not by the invention of any new means whereby the characters of the currents could be changed so that they could pass each other in the line without interfering.

Fig. 307 (2) shows the connections for duplex working by what is called the differential method. As the connections at both stations are exactly alike it is sufficient to consider those at either. At station A, then, we have as in simple telegraphy the battery with its copper and zinc poles, the zinc pole going to earth and the copper to the under contact piece of the key. The lever of the key is connected to the line through the receiving instrument, and the peculiarity of the receiving instrument is that instead of having one wire or circuit (through which the current passes) surrounding the needle, there are two wires wound round the needle in opposite ways, so that when a current passes through both, the effect of one wire on the needle is counterbalanced by the effect of the other, because the same current is flowing in opposite directions through these wires. One of these branches is shown by a full and the other by a dotted line. Let us suppose that the key is put into contact with *a*. The current then flows from the copper pole to *b*. At *b* it has two channels by which to flow through the instrument, viz., by the full wire into the line, and by the dotted wire into what is marked as the artificial line. It is, therefore, split up, and part flows by the full channel in one direction round about the needle, while part flows by the dotted channel in the opposite direction round the needle. Now if these two currents are unequal the needle of the receiving instrument will be moved, and every time the key makes contact at *a*, a signal will be made by the needle. If, however, these currents are equal the needle will not move, no matter how often contact is made at *a*. This, then, is the first step towards duplex working. The operator at station A must join up his receiving instrument, so that although he may be sending currents into the line, he will not thereby affect his own instrument, which will still be free to receive a signal from station B. Now he can only do this by making his artificial line equal, or very approximately equal, to the real line in all its effects on the current. We have seen that at the point *b* the current has two channels to flow through, viz., one by the full branch of the instrument into the line to earth at the distinct station B, and one by the dotted branch of the instrument through the artificial line to earth at the home station A. Now if the resistance and retardation of these two separate channels to earth are alike, the whole current from the battery will divide itself equally between them, and half will flow through the actual line, while the other half flows through the artificial line.

We thus see how it is that the operator at either station arranges that he shall be able to send signals *to* the distant station without affecting his own instrument, and at the same time leaving it free to be affected by signals *from* the distant station.

We have now to consider how it is that these signals are received from the other station, while the operator at A is sending at his station. Suppose then that the operator at station B has also arranged his apparatus, battery, key, receiving instrument, and artificial line, in the same way as the operator at A has done, so that when he sends to A he does not affect his own receiving instrument.

Now for B to send while A is also sending, B must make contact with his key as well as A, and with this result, that no current flows through the line at all. A stops B's current, so to speak, and B stops A's, for B uses the same battery power that A does, and the two currents have the effect of instantaneously stopping each other. But the great point is that B has the power to stop A's current and A the power to stop B's, for it is by this stoppage of A's current that B controls A's instrument, and *vice versâ* by the stoppage of B's current that A controls B's instrument. For so long as A's currents are freely flowing through his instrument, one into the artificial line and the other into the real line, his instrument is undisturbed, but the moment his line current is stopped the balance of effects on his receiving instrument is disturbed: all A's current flows to earth through the dotted branch of the instrument, thus

moving the needle or indicator, and a signal is made. Therefore B has the power to stop A's line current; he has the power to make signals on A's receiving instrument without thereby affecting his own. And, similarly, A, by stopping B's line current, has the power to make signals on B's instrument without affecting his own.

This may be made clearer by the following water analogy. Let us suppose that Fig. 308

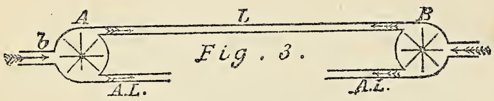


Fig. 308.—Duplex Telegraphy.

represents a plan section of a water pipe of peculiar construction, and that the radial spokes in the bulbs or enlargements at A and B are water wheels. When water at a certain head of pressure (representing the electromotive of the electric current) is forced into this pipe at *b*, part will pass to one side of the water wheel into the channel marked L, and part by the other side into the channel marked A L, and if the sectional areas and frictional resistances of these two channels are equal, half the current will flow one way and half the other. The wheel at A will therefore remain at rest. But the current flowing along the channel L will be free to rotate the wheel at B. We have now only to suppose that water at the same head of pressure is let into the pipe in the same way at B, and to consider what then takes place. Clearly the current from A filling the channel L will be stopped, there will be a greater rush of water through the channel A L, and the wheel at A will rotate. We see therefore that by cutting off or letting on the water at B the wheel at A can be controlled, and similarly from A the wheel at B can be controlled at the same time.

The other important method of effecting duplex working is termed the "bridge method," from the receiving instrument being placed in the bridge wire of a Wheatstone balance. The connections are represented in Fig. 309. Here an ordinary receiving instrument composed of a

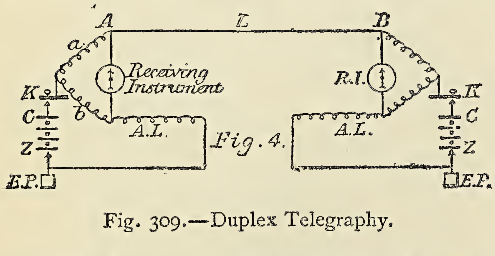


Fig. 309.—Duplex Telegraphy.

single wire surrounding the needle may be used. It is placed so as to bridge across between the line and artificial line. The branch wires which divide the current are here quite distinct from the receiving instrument. The other apparatus are the same as before. The current coming from the key again splits at the branch wires, part goes by the upper branch through the line to earth at the distant station, and part by the lower branch through the artificial line to earth at the home station. And if more goes one way than the other there will also be a current through the cross channel of the bridge, which will move the needle and make a signal. But if the currents are equal in the two channels there will be no flow through the cross channel from one to the other, and consequently no signal will be made. Now, if the resistance of one branch be made equal to the resistance of the other, and the artificial line be made equivalent to the actual line this will be the case, and station A may send as many currents as he pleases to station B without disturbing his own instrument. Again, as in the differential method, when B puts on his current he stops A's line current and disturbs A's electric balance, thereby causing A's instrument to signalise. In the same way A causes B's instrument to signalise.

In applying the water analogy to this case we may consider the two channels to be two parallel mill-races with a cross lead between, in which is placed a mill-wheel. If the loss of head, sectional area, and friction of these two races are equal, a stream of water admitted by a sluice at A will divide itself equally between them, and if the cross channel is made to join two points at the same level there will be no tendency for a permanent current to flow through it and turn the wheel, the channel will fill from both sides, but the wheel will not be turned. If, however, the flow from A along the line race should be stopped, say by shutting a sluice at B, the current from A would be dammed back on itself, the surface level at A would be raised, and there would be a current through the cross channel turning the wheel. Similarly A by damming back B's line current has the power to work B's wheel.

It will be seen from the above that it is very essential that the artificial line should be equivalent, or nearly so, to the actual line in all its effects on the current. For short land lines it has only to be a length of wire which gives a resistance to the passage of the current equal to the resistance of the actual line. But for long land lines (of over 300 miles say), where the inductive action of the earth comes into play, condensers or other device for producing sudden static charges have to be added. On charging a long land line the static charge due to the earth's inductive action is superadded, and for the first moment increases the dynamic or current charge. In the same way on discharging the line the return static charge is again superadded to the dynamic discharge. These static charges and discharges are felt on the receiving instrument as instantaneous currents, and they tend to produce a jerk or "kick" on the indicator of the receiving instrument over and above any slower motion due to the flow of the current. By giving an equivalent static capacity to the artificial line they may be exactly reproduced upon it, and the "kicks" of the actual line may be balanced by the "kicks" of the artificial

line just as the dynamic effects in both are balanced.

For submarine cables this inductive effect becomes very complicated, and it is only very recently that the duplex system has been successfully applied to cables. The inductive effect of the earth is very great in the case of cables, and the sensible retardation and modification of the current throughout the entire length of the line is a very difficult matter to imitate or reproduce. No more application of condensers to the rheostat or resistance circuit of the artificial line will now suffice. Even a uniform distribution of condensers, such as is shown in Fig. 310, will not be sufficient for lines of any considerable length. Not only must the current take the same time to traverse the artificial line that it does to traverse the actual line, but it must be of the same *magnitude* and *form*, it must travel in exactly the same undulation or wave. The difficulty of balancing submarine cables increases in a higher ratio than the length. What is called Muirhead's artificial line furnishes, it would appear, a sufficiently close approximation to the actual cable to allow of practical duplex working on submarine cables. It is a peculiar form of condenser, or rather an inductive resistance, that is to say, it is a resistance circuit which also possesses a certain inductive capacity in the same way that a cable does. Every knot of a cable has a certain specified resistance, inductive capacity, and leakage, so also has this artificial line, and it may be made to have the same resistance, capacity, and leakage per knot that the actual cable has. The resistance part of the circuit is a strip of tin-foil, and this is overlaid by a sheet of tin-foil separated from the strip by an insulator, such as paraffined paper. The sheet of tin-foil is the earth or capacity plate of the arrangement, and represents the "earth" in the case of an actual cable. It appears that by this method the first practical successes in submarine duplex have been attained, inasmuch as in 1877 the balance was effected on the Marseilles-Malta section and on the Suez-Aden section of the Eastern Telegraph Company's lines, and regular working began. The latter cable is 1,460 miles long, and, electrically speaking, one of the longest cables now existing. We may here mention a few of the leading facts in the history of the duplex system.

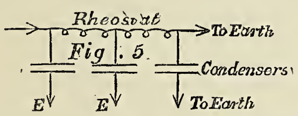


Fig. 310.—Cable Duplex Telegraphy.

In the years 1853 and 1854 Dr. Gintl, an Austrian telegraph director, described and experimented with his system, which is the first known. Gintl employed two separate wires in his receiving instrument, but of very unequal resistance. The wire of higher resistance and greater length led to the line, and the shorter and thicker wire to the artificial line. He used two batteries, a large one to charge the line and signal with, a small one to charge the local circuit or artificial line. These two separate currents were made to balance on the receiving instrument by adjusting the artificial line.

In 1854 Herr Carl Frischen, an Hanoverian telegraph engineer, greatly improved Gintl's plan by modifying it into the differential method, where the wires of the receiving instrument are made equal, and only one battery is used. Messrs. Siemens and Halske subsequently re-invented this method, which sometimes goes by their name. Neither of these methods were, however, as then applied, very successful.

In 1868 Mr. Joseph Barker Stearns, an American electrician, began to revive the neglected duplex system, and since then has achieved considerable success on land lines both in his own country and abroad. He employed the differential and Wheatstone bridge methods, and invented a key which makes the earth connection of the line of unvarying resistance, thus overcoming a defect in Gintl and Frischen's methods, where in working the key in sending the line was sometimes to earth through the battery, sometimes through the artificial line, and sometimes (in Gintl's) not at all. Stearns also applied condensers to the rheostat of the artificial line to counterfeit the induction kicks of the line. It would appear, however, that this had previously been done in England in 1854, in experiments with Frischen's method carried on under a patent by Newall.

In 1873 Mr. Winter, telegraph engineer to the Madras Railway, of Arconum, patented the method of "opposed batteries," in which the batteries constantly oppose each other on the line, and signalling is produced by disturbing the balance by an earth connection.

In 1874 Mr. John Muirhead (of Warden, Muirhead, and Clark, Westminster) patented his artificial line for duplex or submarine cables, and notwithstanding the numerous experiments which have been made within late years to solve this difficult problem in a practical manner, his system has been one of the most successful in practical operation.

Quadruplex Telegraphy.

From the preceding remarks it will be seen that the art of Duplex Telegraphy consists in passing the sending current through the receiving instrument at the sending station in such a manner that it shall, by means of an artificial circuit, divide itself equally between this artificial outlet and the line circuit; when the current thus divided, operating the instrument at the sending station in opposite directions, produces no evident effect upon it, which therefore, so long as the equilibrium is maintained, stands prepared to receive. But a current from, or any derangement of the resistance at the distant station, will at once disturb this equilibrium, and the instrument at the sending station will then be operated by its own current. Thus the apparatus required for duplex working, although

naturally of a slightly more complicated character than that for ordinary direct single working, is by no means of a very complex character.

When, however, we come to the question of quadruplex telegraphy, much of the simplicity of the duplex vanishes. In the latter, A is working to B at the same time that B is working to A; but with the former we have to provide A with a means of working two distinct and independent instruments at B at the same time that B is manipulating two equally distinct instruments at A. Duplex working of course forms a part and portion of quadruplex working—that is, the apparatus at either end is so arranged that it is not affected by the outgoing current so long as the electrical balance is observed, and this is so, no matter what the force of the sending current, or in what way it varies as regards polarity. It is when we come to the question of receiving that the complication which attaches to the quadruplex system enters. To produce independent signals on two independent instruments, we must have two independent methods of signalling at work. If currents of a different potential—say, one giving a force of five, and another of 10—be employed, the two recording instruments may be so adjusted that only one shall be operated by the weak current, whilst both would be operated by the stronger. But in order that these two forces may not vary, it is necessary that the stronger shall be dependable upon the weaker current; that is, that it shall be produced by adding so much to the weaker. Thus, then, the weaker current must be constant. This is so—the weaker current is permanent, and the stronger current is obtained by adding to it at will. The former is manipulated at the sending station by a reversing key, which, in its position of rest, passes, we will assume, a zinc current into the line, but when pressed down for signalling, a copper current. The latter, the increased current, is operated by an ordinary single-current key, which when at rest in no way influences the current passing from the reversing key, but which when pressed down to signal, opens an additional battery circuit, so that at that time, and for the time the single-current key is pressed down, the current manipulated by the reversing key, whether a positive or a negative current, is at the time passing to line, increased by the additional battery power thrown into the battery circuit. The reversing key operates one instrument at the receiving station, and the single-current key the other. It will be observed that actually the latter simply increases or reduces the current which is manipulated by the former.

The receiving apparatus consists of two recording instruments, one worked from a polarised relay by the reversing key, the other direct, or from a non-polarised relay by the increased current brought into play by the depression of the single-current key. The former is adjusted so that it shall work with the weaker current; the latter only with the stronger current. But beyond this the former is only operated so as to produce a recording signal by the copper current, whilst the latter, not being under the influence of a polarised relay, is independent of the polarity of the current and emits its recording signal whenever the current is strong enough to operate it.

The receiving instrument first referred to is of the ordinary double-current principle, and presents no feature of difficulty. It is simple and easy of adjustment. But this is not quite the case with the second or non-polarised instrument. In its adjustment for receiving there is no difficulty, but whenever the polarity of the current is changed a break occurs which disturbs the signal. It is here that the difficulty of quadruplex working is met with, and it is the manner in which Mr. Prescott, in conjunction with Mr. Edison, the well-known American electrician, has overcome this, that he has been able to bring it within practical limits. But it is only done by the introduction of specially arranged local relays and condensers, so adjusted that the one acting upon the other is able to reduce this break by prolonging the one current until the other is able to assert itself. This portion of the apparatus is complex and cumbersome, and requires moreover experience and judgment in manipulation of no ordinary character. Those who may wish to examine it more fully, will find it dealt with in Mr. Prescott's work on "Electricity and the Electric Telegraph."

Not only has quadruplex working been fully established in America, but it has even advanced so far that translation from one wire to another is incorporated with it. In this way New York is enabled to carry on four distinct communications simultaneously with St. Louis, a distance of about 1,100 miles, by means of a quadruplex translator at Pittsburgh, and with Chicago, 1,000 miles, by means of a translator at Buffalo. The Western Union Company have the quadruplex in use upon no less than thirty circuits, and the duplex upon forty circuits, embracing in all 21,917 miles of wire. Various combinations of circuits are made by use of the duplex and quadruplex apparatus; for example, the Boston and Buffalo wire is 550 miles in length. A set of translators is fixed at Albany, 200 miles from Boston, and 350 miles from Buffalo, and the wire is worked as follows:—Boston sends to Buffalo and Buffalo sends to Boston. Boston sends to Albany and Albany sends to Boston. Albany sends to Buffalo and Buffalo sends to Albany, all simultaneously. Similar arrangements are made with other wires in other directions. At Pittsburgh two sides of a quadruplex are connected with a duplex to Baltimore, and the other two sides with a duplex to Philadelphia. This enables Chicago, on the main wire to Pittsburgh, to work duplex with Baltimore and Philadelphia.

The importance of such a system cannot be over estimated. The only question which suggests itself amidst the complicated apparatus necessary to effect it is, whether the practical results obtained render it, with all its attendant expense in the way of experienced operators, expensive apparatus, and highly maintained wires, a commercial success? To estimate the value of such

an invention it would be necessary to show the amount of work—that is, the number of words or number of messages—which it is capable of disposing of in a given space of time. An electrical and a scientific success none will doubt it, and to America, should its application become general, will be due, as was the case with the duplex, the honour of having revived and brought to a practical issue that which hitherto has been but a scientific problem.

Such is an account of two of the most curious inventions that have yet been made in telegraphy. The British Postal authorities have, as already stated, adopted the duplex system on some of the lines in England. As regards quadruplex telegraphy we are not aware that at present its progress has been great in this kingdom, and in fact, even the duplex system has been, and is, but slowly and cautiously adopted. Of course on the face of it, when one wire does the work of two, economy must necessarily arise in the outlay of capital in regard to a line of telegraph. Another point of importance, in this country at least, is a matter of space, for our land lines are becoming so numerous as to lead to great multiplication of wires. In London the underground and overhead wires may be reckoned by scores, and they are constantly increasing in number, and will do so as the lines for private telegraph purposes increase. We have already made extended remarks on this subject in the last Chapter, devoted to British Telegraphy, and have given some interesting statistics in regard to these questions. On the continent the use of underground wires is greatly increasing. The system of underground telegraphy designed by Dr. Stephan, Postmaster-General of Germany, was completed in 1881. On March 14, 1876, the first line of cable from Berlin to Halle was commenced, and on June 26, 1881, the system was completed by laying the cable from Berlin to Aix-la-Chapelle. In 58 months 18 lines have been laid, comprising 3,394 miles of cable, costing 30,200,000 marks (or £1,500,000). The 18 lines connect 221 towns, including the most important places of commerce, and chief fortifications of the German Empire. Ten of these lines were laid by Messrs. Fellen and Guilleaume, of 101, Leadenhall-street, London, and Cologne, Germany; the remainder by Messrs. Siemens and Halske, of Berlin. The conductors in the 3,394 miles of cable have a total length of 23,313 miles. The weight of materials consumed in manufacturing these cables was 12,825 tons, consisting of 10,165 tons of iron, 823 tons of copper, 837 tons of gutta-percha and hemp, and 388 tons of asphalte. In the crossings of rivers 70 cables were required.

Electrical Bells, Alarms, etc.

Electrical bells have now become of universal use not only for telegraph purposes, but also in our offices, houses, etc. They present the great convenience of allowing the conducting wires to be placed anywhere out of the way, and when once properly fixed need never get out of order. Voltaic cells, such as those of Leclanché and others, have been made which will work without recharging for months together. They may be used as thief-detectors, house-protectors, and for an infinite variety of purposes. They present the advantage to those who use them of being kept ringing until their call is obeyed—an advantage perhaps not over highly estimated by those whom they call. Of course for telegraph purposes they are essential as necessary to call the attention of the telegraphist to the fact that a message is about to be sent him. Some excellent illustrations of special forms of alarms and indicators were shown at the Paris Exhibition of 1881, of which the following is a brief description.

The electric current, from its instantaneous velocity, is well adapted either to convey tidings of an outbreak of fire to the post of succour or to warn the inhabitants of a house that the temperature of any particular room has alarmingly increased; and consequently there have been a considerable number of electrical fire alarms devised. The casual nature of fires has, however, prevented their general adoption, and it is only in a comparatively few towns and buildings that we find a system of annunciators. Nevertheless, the time is approaching when every town of importance will have its complete plan of alarms, and all large buildings containing valuable property will be fitted up with local indicators to tell the watchman or the nearest fire brigade station of an outbreak of fire.

There was a number of ingenious fire alarms, both for streets and single houses, in the Exposition of the Palais de l'Industrie, and of the former class perhaps the best was that of Mr. Edward Bright, of London, which has been adopted by the Metropolitan Board of Works for the London Fire Brigade service after a long trial. Numerous street alarm posts have been planted in the City and the Metropolitan districts, and instantaneous calls can be made by them on the Fire Brigade stations nearest at hand. The importance of such a system to the crowded City of London, or any other large town, cannot be over estimated when we remember that a few minutes saved at the beginning of a fire may prevent a ruinous conflagration and loss of life. The principle applied by Mr. Bright is that of the "Wheatstone balance," wherewith electricians are able to test the position of a fault in a submarine cable, and on hearing the alarm bell at the brigade station the officer in charge identifies the street alarm from which the warning was sent, and thus locates the district of the fire. This he does in a very simple manner by inserting resistance into the balance until he compensates the resistance of the alarm circuit, just as a salesman weighs commodities. The street alarms or pillar posts are all joined on a single circuit, and the apparatus has the merit of simplicity. There is no clockwork about it, and it has recommended itself so well to Captain Shaw, that posts are about to be set up in all parts of the metropolis.

In the Swedish Section, Messrs. Ericsson and Sons, mechanicians of Stockholm, exhibited a

model apparatus for striking bells to announce fire in cities. In Sweden only the chief towns have houses built of stone or brick, the rest are usually of timber, and therefore a good system of fire alarms is particularly needful. Indeed, to fight the flames there is a small army of firemen in every city, for every able-bodied man between the ages of 18 and 55 years is compelled by Government to enlist in the brigade. Large water pipes and taps are provided in the streets, and a great number of fire engines are kept in readiness to take the road. In the smaller towns where brigade stations are not kept up, it is customary to ring the church bell to call the men together, and the apparatus of Mr. Ericsson is designed to do this from the street alarm pcst by means of electricity, each impulse of current producing a stroke of the hammer on the bell. The hammer is counterweighted besides the bell, and therefore requires only a small force to move it. Each push of the press-button sends a current, which only makes one stroke, however long the current is kept on, so that to repeat the stroke it is necessary to give repeated pressures to the button. The plan is new, and has been favourably reported on at a congress of fire brigade officials held in Upsala. Mr. Ericsson also arranges his alarm messages to go straight to the police or fire brigade stations and warn the officers there, but there is nothing novel in this application.

The alarm of M. V. Bartelous, 1, Rue du Persil, Brussels, is intended to combine the domestic with the street alarm in such a way as to obviate the intervention of personal aid to call the station. In fact, the fire is made to announce itself to the brigade, whether the people living in the house hear the indoor signal or not. It is clear that this aim on the inventor's part complicates the practical solution of the problem very greatly, and requires the house to be told as well as the district. M. Bartelous's apparatus is ingenious, but its weak point consists in the danger that some of the domestic alarms may not operate. Personal agency is far more reliable than physical devices for telling the outbreak of a fire to a station, though in default of watchmen the latter are useful as annunciators to the inhabitants of a house or ship. The apparatus of M. Bartelous requires to undergo the test of practical experience.

As regards the tell-tales in question for domestic use, there was a number in the Exhibition, but they all operate by the expansion of mercury, or compound metal bars completing an electric bell circuit when a certain danger-temperature is reached, or by ringing the bell when a piece of fusible alloy or tallow is melted. These are well-known devices, and need not be detailed. Mr. E. Bright exhibited a specimen in which the contact is made by a metal bar or spring affected by the heat. Being only about the size of a pill-box, it has this advantage over larger and clumsier ones, that it can be hid in the corner over a ceiling without disfiguring a room. Moreover, it is cleaner than those which depend on the melting of a soft alloy or a piece of tallow, and it is part of its economy that it can be fitted to the same wires which answer for electric bells.

The best alarm based on the fusing of metal at a low temperature was that of M. Bedolière, shown in the stall of the Minister of War. It consists of a spring contact, which is kept open by the interposition of a small round bar of fusible alloy which melts at 53 deg. Cent. (127.4 Fahr.). Whenever the temperature of the room where the alarm is placed rises to this point, therefore, the metal prop runs away and the spring makes contact, thereby ringing an electric bell. The proportions of the alloy are cadmium, one part; tin, three; lead, six; bismuth, eight; mercury, four. An alloy fusible at 68 deg. Cent. is composed of cadmium, one part; tin, $2\frac{1}{2}$; lead, five; bismuth, eight; mercury, one; and when it is required to melt at 77.5 deg. Cent. (171.5 deg. Fahr.), the proportions are cadmium, one part; tin, three; lead, six; bismuth, fourteen; and no mercury.

In the Belgian Section, the tallow alarm of M. L. Brasseur, Rue de Congrès, Brussels, was worthy of remark from the novel part played by the tallow. It is contained in a long narrow tin tube, which is placed side by side with a similar tube, which is left empty. The two tubes are connected together at both ends, so as to form one compound bar, and owing to the presence of the tallow absorbing heat, the empty tube expands most, and drives the combined pair against a contact screw, just as if they formed a composite metal bar.

There were two or three flood alarms in the Exhibition; for example, that of M. Chappuis, 17, Rue Lourmel, Paris, which consists simply of a small cork float enclosed in a little box open at the bottom, and supported on a staff at the height required above the ordinary level of the water; or that of M. Grivolas, of Avignon, which is really a pluviometer intended to register the level of a river or reservoir in centimetres at any distance. It is composed of a zinc ball float, operating a transmitter which sends a current along a single line wire to the recorder.

We may mention here the new annunciator of Mr. Hubbard, exhibited in the American Section by Mr. C. Williams, of Boston, U.S.A., which announces the number of a hundred different hotel rooms by means of twenty wires.

CHAPTER XX.

PHOTOGRAPHY.

OF all the arts that the pursuit of science has given to man, the most popular is, without doubt, Photography. In its practical pursuit it has engaged the attention of, and amused thousands who have neither the knowledge of nor the taste for science. In its most important application—that of taking likenesses, views, etc.—it is universally appreciated and equally sought after; it frequently forms the amusement of those who consider it a valuable adjunct to an amateur pursuit of drawing, painting, etc.; to the professional artist it is invaluable; and to the philosopher, in its application to astronomy, and many other branches of science, it has become a necessity. It is as easy now to take the likeness of the sun, moon, etc., as to produce one of our fellow creatures, and by its application to research by spectrum analysis we have been enabled to dive into the secrets of the mechanical and chemical constitution and phases of matter with an extent and accuracy that is really wonderful in the eyes of even the philosopher.

Yet this branch of applied science is comparatively new; in fact, we may include photography, the electric telegraph, and many of our most important scientific applications, in a history barely of more than half a century. But it will be impossible to go into the history of this art, for its inventors and improvers are indeed "legion." Suffice it to say that we are indebted to Wedgwood and Sir Humphry Davy for the initiative of our processes; and since their day Niepce, Daguerre, Talbot, Archer, Sir John Herschel, and a host of other eminent men, have thrown in their talents, either to investigate the science or to improve the processes of the art, and it is by the combination of these two kinds of workers that we have attained our present perfection.

But, in the first place—What does photography mean? The term derived from the Greek word simply means to write, draw, or picture by light acting on certain substances capable of being chemically affected by its rays.

The power of light in changing the ordinary colour of objects is far more universal than is generally supposed. Most of our readers must have noticed that some delicate colours speedily fade when exposed to the full light of the sun. This effect is undoubtedly due to some action produced by the rays of light on the substances with which a material has been dyed. Light-blue and pink silks are thus easily faded. Sir John Herschel, in some masterly researches, published a few years ago in the Philosophical Transactions of the Royal Society, pointed out that all the juices of any flower are thus acted on by light. Indeed, we may state generally that the cause of the varied colours of our landscapes and flowers is largely that of a process analogous to those employed in photography. One of the simplest illustrations of the kind we can offer, is that of the different appearances of the inside and outside of some vegetables such as celery, lettuce, and the cabbage. The external leaves, which have been freely exposed to the direct solar rays, have a deep green, or, in celery, a red colour; whilst the inner leaves, which have been protected from light, always present a pale or blanched appearance. Even the human face may be taken as another instance of the same kind; for we observe the ruddy glow and deep colour in the rustic, presenting a bright contrast to the sallow, pale, and unhealthy appearance of the factory operative, or the resident of our large cities. Light, indeed, has a colourising and a sanitary effect, to an extent little dreamt of by those unacquainted with the science of physiology.

That it is light which causes these varied changes in the vegetable world has been placed beyond doubt by the masterly researches and interesting results Dr. Siemens obtained by means of the electric light alone. An abstract of a paper read by him before the British Association at York, in 1881, has been given at p. 583, *et seq.*, when we treated on the electric light. It will be there seen that during the entire absence of sun, or any other but the electric light, he was able to grow peas, beans, and various culinary vegetables, etc. But his great success laid in the production of semi-tropical and tropical fruits, such as the melon, pineapple, and banana, which equalled, and indeed in some respects excelled, similar fruits grown in what may be called their native climates. It will be evident that light alone, as produced by electricity, was the immediate cause of his success, and thus we have ample proof of the effects of light not only on the growth, but also the colour of vegetable productions.

Photographers, however, avail themselves almost entirely of the metal silver and its compounds as the great medium of their operations. When that well-known metal is united with certain substances, the resulting compounds are rapidly affected by light; and on exposure thereto become changed to a dark colour. The whole art of photography may be almost summed up as existing in the choice of the salts of silver,

their proper application, and immediate removal when the desired effect is gained. It is true that many other substances may be similarly employed, but, in practice, they are of comparatively little independent worth.

In the following pages, while endeavouring to be chiefly practical, it will not only be desirable to explain the scientific laws on which the success of the processes immediately depend, but also to give an exposition of those which primarily influence the result. It will, therefore, be evident that the whole subject, so far as the science and practice of Photography are concerned, may be embraced under two heads, viz., the *Physical*, in which we must study the laws and influences of the agent, light; and the *Chemical*, whereby we have to apply the laws of chemistry by the choice and manipulation of certain chemical compounds within our reach.

Light.—This is generally included with what are called imponderable agents by old writers, but the term is simply a convenient method of hiding our ignorance by the use of cumbrous and indeed pompous language. We know a piece of iron by being able to understand its physical characters, such a weight or specific gravity, tenacity, hardness or softness, etc., and other qualities that are familiar to us all. By such knowledge we can institute comparisons between it and other metals, and distinguish them for certain purposes. But of light, heat, electricity, and magnetism we literally know nothing except by their effects. They are *mutually producible*, as we have abundantly shown in the preceding Chapters on electricity in this volume, the agent employed for such purposes being *motion*. It is often said in scientific works that they are *convertible into each other;* but in a philosophical point of view this is incorrect.

If the reader refers to page 86, *ante*, in the present volume, under the head of dyeing, etc., he will find a general exposition of the laws of colour, so far as it relates to the art of the dyer. But the photographer must proceed farther in his researches for the influence that gives him success. Until a comparatively recent date, the constituents of the solar rays were supposed to be merely light and heat; but a third agent, now called *Actinism*, has been discovered. Scheele, the Swedish chemist, was the first to investigate the peculiar conditions under which the change of colour of the chloride of silver takes place, and determined the difference in the action of the least and the most refrangible spectral rays as produced by the spectrum afforded by the prism. Bérard afterwards proved that the most luminous of the prismatic rays would not, even when concentrated by a lens, blacken chloride of silver in twenty minutes; whereas the least luminous rays at the most refrangible end of the spectrum, condensed in the same manner, produced a great degree of darkness on the chloride in a few seconds. In 1803, Wedgwood, the celebrated porcelain manufacturer, employed the chloride and nitrate of silver, spread on paper and white leather, for copying the coloured glass pictures in church windows, but he failed to give permanence to the impressions he produced. Between 1814 and 1827, M. Niepce, of Chalons-sur-Saône, was employed in investigating this subject, and discovered that resin spread on metallic or glass tablets was sensitive to solar agency, the parts exposed becoming more soluble than those in shadow. By this means he was enabled to produce pictures upon silver tablets by the use of the camera obscura. Niepce, in 1829, associated himself with Daguerre, who had previously commenced some independent observations; and their combined experiments led to the discovery of the Daguerreotype.

But even so far back as the year 1801, Ritter of Jena, made the important discovery, whilst repeating the experiments of Scheele, that on throwing the prismatic spectrum on a sheet of paper impregnated with chloride of silver, that not only was the blackening or chemical effect more powerful at the violet end of the spectrum than at the red, but that the effect was greatest of all beyond the limits of the violet, consequently beyond the luminous boundary of the spectrum. This discovery soon gave rise to the idea that some agency distinct from heat on the one hand, and light on the other, must exist in the radiant spectrum. Almost contemporaneous with the discovery of Ritter of the existence of what is now called *Actinism*, Sir William Herschel was prosecuting a course of experiments to manifest the distinction in the prismatic spectrum between rays of heat and mere luminosity. In the year 1800, while making some experiments on coloured glasses, intended for the purpose of defending his eyes from heat, while examining the sun with his large telescope, he found that a deep red glass, notwithstanding the obstruction of a large amount of light, scarcely, if at all, interfered with the passage of heat. On the other hand, a blue or grey glass defended his eye completely. On looking more narrowly into the subject, Herschel proved for heat what Ritter had previously done for actinism—that not only of all the coloured portions of the spectrum did red afford the greatest amount of heat, but the maximum point of spectral heat was developed altogether beyond the red. Thus it seems that the decomposition of radiant matter by the prism may be indicated, as in the following diagram, where the three recognisable effects of heat, light, and *actinism*, or chemical power, are represented by three distinct but mutually intersecting series of waves.

It will be observed, from a careful examination of this diagram, that while heat (*a*) and light (*b*) have each one point of concentration, actinism (*c*) has two. Examination of the spectral chart, as the diagram may be termed, will also tend to create the supposition, which certain practical observations go to confirm, that the three agencies, heat, light, and actinism, are mutually antagonistic to each other. So far as light and actinism are concerned, M. Claudet has proved that yellow, the point of greatest light, is not only negative, but positively destructive to actinic power.

It will be evident from the perusal of the preceding remarks that the subject of actinic radiation is of especial interest to the photographer, and in fact lays at the very foundation of the practice of his art. It is much to be regretted that the subject was long neglected before its philosophical aspects were reduced to a practical form.

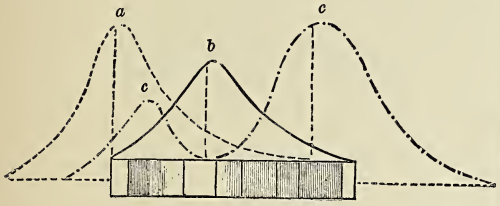


Fig. 311.—Actinic Rays of Light.

Bearing on this subject, a most interesting discovery was made many years ago that has an important connection with light and actinism in relation to photography. It is Luminous Epipolic Dispersion.

The term epipolic dispersion was first applied by Sir John Herschel to indicate a series of phenomena, which were also studied by Sir David Brewster, but still more carefully by Professor Stokes, of Cambridge. This latter philosopher arrived at some very important conclusions relative to the class of phenomena in question; the most striking of which being, that the prismatic spectrum is not composed of the three different agents, heat, light, and actinism, but probably two, light and actinism being different functions of the same; and it may be that even the heating part of the spectrum is only a third variety of manifestation of one and the same agent.

In anticipation of the experiments by which Professor Stokes arrives at his conclusions, it may be here stated that he imagines his investigations warrant the conclusion that the refrangibility of light for each colour is not fixed and invariable as, since the time of Newton, has been universally imagined, but that light of one colour admits of being changed, under certain circumstances, into light of another colour; and, more curiously still, that the actinic or non-luminous part of the prismatic spectrum admits, under certain circumstances, of being rendered visible.

The phenomenon to which the attention of Sir J. Herschel was first directed in relation to epipolic dispersion of light, is one that most persons will have noticed. If a weak solution of disulphate of quinine in water, slightly acidulated with sulphuric acid, be looked at under certain conditions of daylight, a peculiar blue opalescence will be observed to pervade its surface, and to extend a short way down into its bulk; but if the light, which has once been transmitted through a solution of sulphate of quinine, be made to impinge on another solution precisely similar in all respects, the original phenomenon will not be repeated,—thus leading to the inference that (to use a popular expression) some peculiar quality of the light has been removed, or strained away.

In one experiment performed by Sir J. Herschel, in which sunlight was used, a pale blue flame extended to nearly half an inch from the surface. As regards the dispersed light, this, when analysed by a prism, was found to consist of rays extending over a great range of refrangibility; the less refrangible extremity, however, of the spectrum was wanting. The dispersed light, on being analysed by a tourmaline, showed no signs of polarisation. Another experiment showed that the dispersed light was perhaps incapable, at any rate not peculiarly susceptible, of being again dispersed.

Such is the nature of the phenomenon as evidenced by a solution of disulphate of quinine; numerous other bodies, however, both solid and liquid, manifest a similar property. Some time before the attention of Sir John Herschel had been drawn to the peculiar phenomena of blue epipolic dispersion in a quiniferous solution, Sir David Brewster had noticed a peculiar exhibition of red light by certain green vegetable solutions—the green matter of leaves, for example. In this case the colour is not limited to a thin stratum of the surface, as is the case with a quiniferous liquid; but Professor Stokes, nevertheless, considers it to be a phenomenon of the same kind. In both cases the curious point for contemplation was this:—A ray of light by passing across a stratum of liquid was deprived of the power to reproduce the original effect; still, in no other respect did it appear to be altered. "I found myself, therefore," remarks Professor Stokes, "fairly driven to suppose that the change of nature consisted in a change of refrangibility. From the time of Newton it had been believed that light retains its refrangibility through all the modifications which it may undergo. Nevertheless, it seemed to me less improbable that the refrangibility of light should have changed, than the undulatory theory should have remained at fault. We have only to suppose that the invisible rays beyond the extreme violet give rise, by internal dispersion, to others which fall within the limits of refrangibility, between which the retina of the human eye is affected, and the explanation is obvious. The narrowness of the blue band observed by Sir John Herschel would merely indicate that the fluid, though highly transparent with regard to the visible rays, was nearly opaque with regard to the invisible ones. According to the law of continuity, the passage from almost perfect transparency to a high state of opacity would not take place abruptly. We should thus, too, have an immediate explanation of a remarkable circumstance connected with the blue band—namely, that it can hardly be seen in strong candle-light, though readily seen by even weak daylight; for candle-light, as is well known, is deficient in the chemical rays situated beyond the extreme violet."

Although a solution of disulphate of quinine

is the body in which the phenomena of internal luminous dispersion were first studied, it is by no means the only one ; nor is it even that in which the phenomenon in question is most strikingly developed. The following list comprehends some of the substances in which the quality of internal luminous dispersion is most observable :—

LIST OF HIGHLY SENSITIVE SUBSTANCES.

Glass, coloured by peroxide of uranium, yellow uranite, nitrate or acetate of the peroxide. Probably various other salts of peroxide would do as well. The absorption bands of the salts, whether sensitive or not, of peroxide of uranium, ought to be studied in connection with the change of refrangibility.

A solution of the green colouring matter of leaves in alcohol. To obtain a solution which will keep, it is well previously to steep the leaves in boiling water. The alcohol should not be left permanently in contact with the leaves, unless it be wished to observe the changes which, in that case, take place ; but poured off when the strength of the solution is thought sufficient. Also the solution, when out of use, must be kept in the dark.

A weak solution of the bark of the horse-chestnut.

A weak solution of sulphate of quinine—*i.e.*, a solution of the common disulphate, in very weak sulphuric acid. Various other salts of quinine are nearly, if not quite, as good.

Fluor spar (a certain green variety).

Red sea-weeds, of various shades; a solution of the red colouring matter in cold water. If a solution be desired, a sea-weed must be used which has never been dried.

A solution of the seeds of *Datura stramonium* in alcohol, not too strong.

Various solutions obtained from archil and litmus.

A decoction of madder in a solution of alum.

Paper washed with a pretty strong solution of sulphate of quinine, or with a solution of stramonium seeds, or with tincture of turmeric. The sensibility of the last paper is increased by washing it with a solution of tartaric acid. This paper ought to be kept in the dark.

A solution, not too strong, of guiacum in alcohol.

Safflower-red, scarlet cloth, substances dyed red with madder, and various other dyed articles in common use.

Out of the above list we may remark that the first—glass coloured with uranium—is largely used in photography for cutting off rays, so that all but a portion of the likeness, etc., may be prevented from appearing by which the head or bust alone is represented in the photograph. These are known as cameo portraits.

Another and most important subject directly connected with those which we have just discussed, is that of certain phenomena presented by the spectrum. It was long ago discovered that when the spectrum as afforded by the prism was carefully examined by a powerful telescope a number of black or coloured bands appear that have now been ascertained to exceed 1,000. Each of these is characteristic of some metal or other body in a luminous or incandescent state. To Messrs. Bunsen and Kirchkoff we are indebted for the discovery of a new method of analysis, termed spectrum or spectral analysis, which has produced some astonishing discoveries in connection with matter, whether in the earth or in the planets. Spectra photographs in fact have been taken of the sun, moon, the planets, some of the fixed stars, and still more recently (1881) of comets, that have led to speculations as to the material character of these heavenly bodies of the most interesting kind. Our space will not allow of us entering into a lengthened disquisition on the subject ; we shall, therefore, here confine our remarks to the practical details and results obtained by the photographic spectra of the electric light in contrast with those of the solar rays. We may state, however, that metals such as iron, barium, strontium, sodium, etc., etc., which are capable of incandescence, have all been experimented on and their places assigned them in the spectrum. Having obtained these facts, we are enabled to test both terrestrial and celestial bodies, for the presence of such substances. Gases, etc., have been similarly dealt with, and in fact most bodies which can in any way produce a flame ordinarily, or be made to do so by intense heat.

A plan of the apparatus by which the spectra may be photographed is shown in the figure (Fig. 312). It consists of an ordinary camera-obscura, C, attached to the end of a long wooden tube, A, which opens into a long cylindrical box, B, within which is a prism of heavy flint glass, or of bisulphide of carbon, *i*. At *l* is a lens of fifteen inches focal length, and at *s* is a slit parallel to the axis of the prism. The slit is adjusted so that it shall be distant from the lens 30 inches, or twice its focal length, and the screen of the camera is at an equal distance from the lens. The prism can be turned round its own axis by the lever, *d*, and the tube, A, can be adjusted so as to vary the angle with the brass tube, *e*; a small reflecting prism is, when necessary, placed so as to cover half the slit, *s*, and to reflect light from a second source so as to form a second spectrum on the plate, as in Steinheil's apparatus.

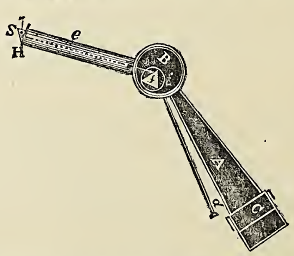


Fig. 312.—Apparatus for Photographing Spectra.

If the prism be so adjusted as to throw the solar rays reflected from a heliostat upon the screen of the camera, the wires which transmit

the sparks from a Rhumkorff's coil are placed in front of the uncovered portion of the slit, and the two spectra are simultaneously impressed. The solar beam is easily intercepted at the proper time by means of a small screen, and the electric spectrum is allowed to continue its action for two, three, or six minutes, as may be necessary.

Although with each of the metals—including platina, gold, silver, copper, iron, bismuth, cadmium, zinc, aluminum, magnesium—when

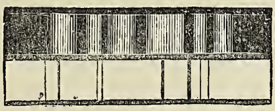


Fig. 313.—Platina and Solar Spectra.

the spark was taken in air, decided photographs were obtained, it appeared that in each case the impressed spectrum was very nearly the same, proving that the lines produced were not those which were characteristic of the metal, but that they were the lines due to the incandescence of the air. These bright lines, it is important to observe, do not correspond to any black lines in the solar spectrum, apparently indicating the absence of nitrogen in the solar atmosphere.

The peculiar lines of the metal seem to be chiefly confined to the *visible* portion of the spectrum, and these have little or no photographic power.

Metallic Spectra, showing Corresponding Bands.

Fig. 314.—Gold Spectrum.

Fig. 315.—Silver Spectrum.

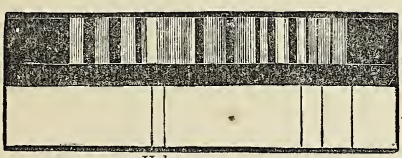


Fig. 316.—Copper and Solar Spectra.†

Fig. 317.—Iron Spectrum.

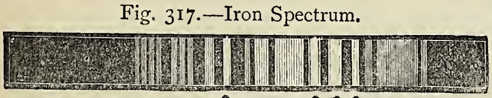


Fig. 318.—Zinc Spectrum.

This was singularly exemplified by repeating the experiments upon the same metal in air, and in a continuous current of pure hydrogen. In these experiments two iron or platina wires were sealed into a bulb blown upon a long narrow tube which conveyed the gas under trial. Under these circumstances, for example, iron gave in hydrogen a spectrum in which a bright orange and a strong green band were visible, besides a few faint lines in the blue. Although the light produced by the action of the coil was allowed to fall for ten minutes upon a sensitive collodion surface, scarcely a trace of any action was perceived (Fig. 319), whilst in five minutes in the air, a powerful impression with numerous bands was obtained (Fig. 317).

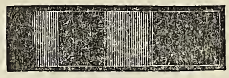


Fig. 319.—Iron Spectrum in Hydrogen.

Similar results were obtained with platina (Figs. 320 and 313). When carbonic acid was substituted for hydrogen, maintaining a continuous current of the pure gas during the whole experiment, the effect upon the sensitive plate was scarcely more marked.

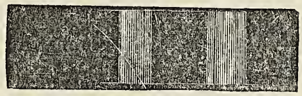


Fig. 320.—Platina Spectrum in Hydrogen.

No photographic impression was obtained in ten minutes of the brilliant red line produced by sending the discharge of Rhumkorff's coil through one of Geissler's hydrogen vacua.

Fig. 321 shows a copy of the photographic spectrum produced by the violet line of light obtained from one of Geissler's nitrogen vacua. The lines produced by the different metals which are characteristic of them, are best displayed by using, as Wheatstone did originally, somewhat feeble electrical discharges. When, for instance, the Leyden jar is introduced into the secondary current of the Rhumkorff's coil, as practised by Grove, the light is principally produced, as Alter and Angström have shown, by the ignition of the atmospheric air, and particularly by the nitrogen. The spectrum will appear to be filled with brilliant lines, which are nearly the same, whatever electrodes are used; but if the Leyden jar be removed, the characteristic bands of the metals may be distinctly seen. Those of iron are only well seen when the metal is red-hot, but not actually burning.

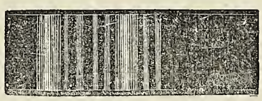


Fig. 321.—Nitrogen Vacuum Spectrum.

Most of the metals give, as was remarked by Masson, a feeble continuous spectrum streaked by bright bands of varying intensity; and this sombre ground is not due to the ignition of the electrodes, as may be at once seen by the instant change presented in the appearance of the spectrum, if one of the electrodes does become incandescent.

It was early remarked by Mr. Talbot, that, in the spectra of coloured flames, the nature of the

† Focus rather shorter than that of other photographs.

acid did not influence the position of the bright lines of the spectrum, which he found was dependent upon the metal employed; and this remark has been confirmed by all subsequent observers.

But the case is very different in the absorption bands produced by the vapours of coloured bodies. There the nature of both constituents of the compound is essentially connected with the production of absorption bands. Chlorine combined with hydrogen gives no bands by absorption in any moderate thickness.

Chlorous acid and peroxide of chlorine both produce the same set of bands; while hypochlorous acid, although a strongly coloured vapour, and containing the same elements, oxygen and chlorine, produces no absorption bands. Again, the brownish-red vapours of perchloride of iron produce no absorption bands; but iron, when converted into vapour in a flame, gives out bands which are independent of the form in which it occurs combined.

These anomalies appear, however, to admit of an easy explanation, if we suppose that in every case the compound is decomposed in the flame, either simply by the high temperature, just as Grove has shown that water is. In other cases of the production of bright lines by the introduction of a metallic salt into the flame of burning bodies, the reducing influence of the hydrogen, and other combustible constituents of the burning body, would decompose the salt, liberating the metal, which, after producing its characteristic lines, would immediately become oxidised, and be carried off in the ascending current. In the voltaic arc this decomposition must of necessity take place by electrolytic action.

The compound gases, protoxide and deutoxide of nitrogen, give, when electrified, the same series of bright bands as Plücker has shown, which their constituents when uncombined furnish. Aqueous vapour always gives the bright lines due to hydrogen, and hydrochloric acid the mixed system of lines which would be produced by incandescent hydrogen and chlorine.

There is obviously a marked difference between the effect of intense ignition upon most of the metallic and non-metallic bodies.

The observations of Plücker upon the spectra of iodine, bromine, and chlorine, show that they give, when ignited, a very different series of bands to those which they furnish by absorption, as Dr. Gladstone has already pointed out; but it is interesting to remark, that in the case of hydrogen, which, chemically, is so like a metal, we have a comparatively simple spectrum, in which the three principal bright lines correspond to Fraunhofer's dark lines, C, F, and G (Plücker). It is, however, to be specially noted, that hydrogen occasions no perceptible absorption bands at ordinary temperatures in such thicknesses as we can command in our experiments; and the vapour of boiling mercury is also destitute of any absorptive action, although mercury, when ignited by the electric spark, gives a characteristic and brilliant series.

The following experiment suggested itself as a direct test of Kirchkoff's theory:—Two gas-burners, into which were introduced chloride of sodium on the wick of a spirit-lamp, were placed so as to illuminate equally the opposite sides of a sheet of paper partially greased; the rays of the electric light, screened from the photometric surface, suitably protected, were made to traverse one of the flames. If the yellow rays of the light were absorbed by the sodium flame, the light emitted laterally by the flame should be sensibly increased. The experiment, however, failed to indicate any such increase in the brilliancy of the flame, possibly because the eye is not sufficiently sensitive to detect the slight difference which was to be expected.

From a perusal of the interesting facts afforded by an eminent experimentalist, our readers will perceive that every solid body, when brought into a state of vapour and incandescence, produces definite and decided effects in reference to the bands of the spectrum. Each body, in fact, has a spectrum of its own; the perfection and constant identity of which is preserved, provided no other interfering cause be present. Great precautions, however, are required in performing the experiments, especially by those persons who may not be accustomed to delicate investigations. Even solid but invisible bodies floating in the atmosphere may invalidate the result; and, under certain circumstances, the minute portion of common salt often present in the air has produced a spectrum, of the sodium kind, much to the perplexity of the observer. It must be borne in mind that this method of analysis is so excessively refined and exact, that *every* possible precaution may fail in affording results which might be expected; and substances in proportions so small as to defy all other means for their detection, may intrude themselves, and so modify the spectral appearances.

The spectrum analysis has been extensively investigated and employed by many eminent observers; and its indications have been used in numerous branches of research in various departments of optical science. All luminous bodies may be examined by it; and if the results are compared with certain standards previously obtained, inferences may be drawn with respect to the colour of light and its cause, which would be utterly unattainable by any other means. For instance, much dispute respecting the nature of the solar rays and atmosphere has been prevalent, and numerous theories have been advanced to account for the production of both the heat and light of the sun. By means of the spectrum analysis, however, Professor Airy, late Astronomer Royal, did not hesitate to affirm that the surface of the sun is in a state of strong incandescence; that immense bodies of vapour are constantly arising therefrom; and even the spectrum produced by iron in the state of vapour has been distinctly noticed in the solar light.

In a similar manner, the light of the planets, fixed stars, comets, etc., is readily examined, and compared with that of the solar rays as already stated. A new means of investigation is thus

put into the hands of the philosopher. The astronomer, the mathematician, and the chemist, are thus jointly called in to determine some of the most interesting problems of astronomy. The theories and facts of each branch of science are thus correlated; the deductions of each are checked or modified by each other; and both the chances and sources of error are diminished in a wonderful and satisfactory manner.

To those of our readers who may be desirous of repeating the experiments, we may mention that complete apparatus for the purpose is now made by the leading philosophical instrument-makers, in which all the requisite minutiæ of construction, etc., are fully attended to. This method of analysis is, therefore, within reach of any one possessing a tolerable acquaintance with optical and chemical science; and will doubtless prove a source of extensive discovery in physical science generally.

Like all new inventions, its use may occasionally lead to crude and indigested theories. In the hands of many observers, however, that evil will meet with its own correction. It is more than likely that the spectrum analysis will prove, in a physical point of view, as beneficial and useful an adjunct as did the invention of fluxions, or the differential calculus in the mathematical department of astronomy and allied sciences.

We have thus traced some of the most important, and, to many, the most recondite laws of light that affect the art of photography, and now pass on to certain chemical conditions, which are essential to the practice of that art.

As some of our readers may be unacquainted with the science of chemistry, it will be necessary to enter, in many cases, into minute details, and the following pages will, so far as possible, be devoted to describing the various processes in all their details, so that even the tyro in science need not get astray in practice if he will carefully follow the instructions that are given.

We commence by introducing the experimenter to a few illustrations, which will give a general idea of the nature of photographic processes, and which he will do well to repeat until a certain amount of ease in manipulation is gained. We must, however, preface our remarks by urging on all a great point, without attention to which all attempts at photographing must surely fail: we refer to *scrupulous cleanliness*. Neglect of this, and carelessness, are the two chief causes of all the disappointments both of the tyro and practised operator; and to impress the necessity of our advice being attended to, we shall suggest an experiment, by which the cleanest hands may be proved to be photographically dirty on many occasions.

Experiment 1.—After washing and drying the hands in the usual manner, allow them to remain some time in distilled water, afterwards frequently rinsing them therein. Add to the water a solution of nitrate of silver: in a short time the water will assume a milky appearance, owing to the common salt, exuded with the perspiration from the skin, forming a substance with the silver, called chloride of silver. If a little of the solution of nitrate of silver be added to pure water, no effect of the kind we have named will be produced.

It will thus be seen how, in every case, the photographer carries with him the instruments of his own destruction. Whenever a piece of paper or glass is touched by the fingers, then a spot of common salt, grease, and organic matter is left: these acting on the silver salts, produce patches and spots which spoil any photograph. We trust that our readers will be by this fully persuaded of the necessity of care in this respect, and thus prevent the numerous annoyances to which their neglect would otherwise expose them.

The substance formed by Experiment 1 is called the chloride of silver, because the chlorine in the common salt from the hand has joined with the silver contained in the nitrate of that metal. We must here state, that the term "salt" is applied by the chemist to a vast range of substances; and generally, whenever an acid is united with an earth or an alkali, a "salt" is formed. Thus nitre, or saltpetre, is composed of nitric acid and potass, and is called a salt of potass. Its name is partly derived from the acid, the nitric, and partly from the base, the potass. Hence the chemist terms it the nitrate of potass; and by this system of naming salts he instantly sees, by the name, what the salt is composed of. Our common table-salt is called, in chemical language, chloride of sodium, because it is composed of a gas called chlorine, which produces the smell of bleaching powder, with a metal called sodium, found in soda, etc. The reader having mastered this system, will at once see its great value; and although perhaps experiencing at first some difficulty in acquiring names of salts, he will speedily reap the advantage of the general nomenclature.

To save repetition of terms, we shall, in future, call a solution of the salts of silver, *the silver solution;* and solution of common salt, *the salt solution;* and for our introductory experiments, these may be made as follows:—

To make the "Silver Solution."—Dissolve fifty grains of crystallised nitrate of silver in one ounce of distilled water.

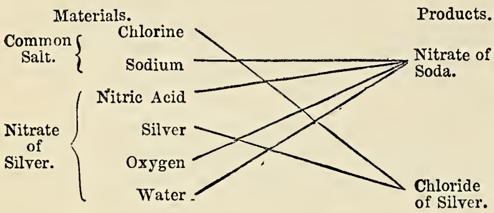
To make the "Salt Solution."—Dissolve sixty grains of common salt in four ounces of distilled water.

It will be observed that we have mentioned that *distilled* water must be employed to dissolve the nitrate of silver. This is because river and spring water contain common salt. Distilled water may be procured of the chemist and druggist, or may by made by affixing a long pewter tube to the spout of an ordinary tea-kettle. As the steam passes from the kettle it will be condensed in the tube, if the latter be kept cold by means of wet rags, or by being immersed in cold water. The distilled water may be received in clean glass vessels, which should be kept stoppered and free from dust.

The solution of the salts of silver should always be kept in a glass-stoppered bottle, and surrounded with a piece of black paper, or kept

in a dark place, so as to prevent the action of light, which of itself would blacken the solution.

Experiment 2.—Pour some of the salt solution into a wine-glass, and then add a few drops of the silver solution. A heavy, curdy, white substance, or precipitate, will fall down, which is the chloride of silver. The chemical change which takes place is illustrated by the subjoined diagram, wherein the materials are named on the left, and the products on the right side.



The result of the mixture is, that the chlorine and silver unite together to form the chloride of that metal; and the nitric acid, sodium, and water form the salt, nitrate of soda, which is dissolved in the liquid. We have thus an instance of chemical decomposition, and the formation of new compounds.

Experiment 3.—Divide the white powder obtained in the last experiment into two portions, and keep one part in a dark place, and expose the other to the rays of the sun. In a short time the portion left in the light will turn to a dark mulberry tint, owing to the action of the chemical rays on the salt; whilst that kept in a dark place will remain entirely unchanged.

By these experiments the student will learn the elementary principles of the art of photography, which is that of producing compounds of silver with other substances that will change colour by the action of light; and may now proceed to the next step, that of preparing paper which will be sensitive to the action of light.

Experiment 4.—*To prepare Sensitive Paper.*—Pour the salt solution into a clean plate, and place on its surface a piece of white writing-paper, leaving it there for some time, so that the solution may enter the pores of the paper. The salted side should then be marked with a black-lead pencil, so as to distinguish it from that which is unsalted. The paper may then be hung up to dry. The next process is to render the paper sensitive to the action of light; and is effected by placing the salted side, face downwards, on the silver solution contained in a clean plate, and leaving it there for about ten minutes. The paper is then to be dried in a place *to which light has no access.* This part of the preparation of the paper should be done by candlelight; and several sheets may thus be made and kept, till required, in a portfolio or book.

Paper thus prepared will at once change its colour on being exposed to diffuse daylight, or the sun's rays; and if any opaque object be placed over it, a complete copy of its form may be procured. If a penny-piece, for instance, be placed on a sheet of this paper, and exposed to sunlight, all the uncovered portion will be turned to nearly a black colour; whilst that under the coin will retain a white and unchanged appearance, because there no light has reached, and therefore no chemical effect could take place. On removing the coin, the white part will become changed, if exposed to the light; and this introduces us to another process—namely, that of "fixing" the picture obtained as above.

The *fixing process* is intended to dissolve away that portion of the silver salt which has not been acted on by the light; and it will thus prevent a picture, when obtained, from being spoilt or lost. The solution used for this purpose is that of a salt called hyposulphite of sodium, an ounce of which may be dissolved in four ounces of water. The picture is to be left on this solution, face downwards, for a short time, and afterwards well washed in abundance of cold water. After being dried, it may be exposed, without any danger of undergoing further change; in fact, it becomes permanent and unalterable. If, instead of a coin, a piece of lace, a fern-leaf, or other such object, be placed on the paper, and pressed thereon by means of a piece of plate-glass, a complete copy of it may be taken: a child's transparent slate is a very convenient arrangement for this purpose; but the ground-glass plate must be replaced by a piece of window or plate-glass, so that the light may freely pass through. By this simple plan a vast number of objects may be copied; the solid parts being represented by white spaces, and the transparent portions by dark marks on the paper. This process is so exceedingly easy, that any young person may readily follow the directions we have given. We may here remark on the advantages which elementary science affords in training and disciplining the young mind. The ordinary course of juvenile instruction has the twofold object of teaching facts and preparing the mental powers for future and more exact studies. If, however, we can find any means by which amusement, interest, and instruction can be combined, such become a most valuable adjunct to an educational course.

We have now to notice that there are two classes of photographs, namely, *negative* and *positive.* By the former, the dark portions of the object are represented by light parts in the picture; but in a positive, the appearances are the same as in the object which has been copied. Fig. 322 represents a negative, and Fig. 323 a positive, of the same object.

A positive picture may easily be obtained by placing a negative, face downwards, on another piece of prepared paper, and proceeding as before. The light will thus pass through the unchanged portions of the negative, and so produce a darkening of the paper beneath it; whilst the dark portions of the negative, of course, prevent any change in that part of the paper beneath them. The positive, thus obtained, may be fixed by the process previously described.

We have purposely restricted these experi-

ments to the simplest form of photographic practice. The materials are easily obtained; and if the process be repeatedly performed, the student will gradually acquire an expertness, and, at the same time, meet with difficulties which he may easily overcome. If, for instance,

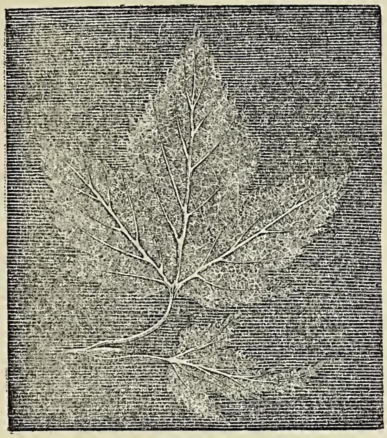


Fig. 322.—Negative Photograph.

he observe brown marks on the picture, he may guess that his fingers have been their cause. White round spots indicate places where neither the salt nor silver solution have touched the surface of the paper, owing to the presence of air-bubbles. Blotches, and large patches on the surface, show that the paper is not suitable

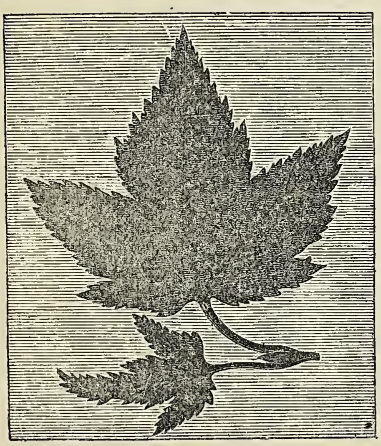


Fig. 323.—Positive Photograph.

for the purpose. This may easily be avoided by the purchase of an article specially prepared for photography; but we still recommend that the tyro should begin in the simplest manner, and so arrive, step by step, at success, by becoming gradually acquainted with obstacles as they accidentally present themselves.

To save trouble, and to simplify our instructions in these elementary attempts, it may perhaps be as well that we give a recapitulation of the whole of the process; and also special directions for obtaining positive copies from negative pictures.

1. Salt one side of the paper, taking care that no air-bubbles are left between its surface and the liquid.
2. Mark the salted side.
3. Dry the paper.
4. Render the salted side of the paper sensitive by placing that surface in the silver solution for about ten minutes, taking precautions against the presence of air-bubbles by drawing the paper over the solution whilst holding it at one corner. This must be done by candle-light.
5. Dry the paper in a dark place, and, when dry, keep it out of the light.
6. To obtain a negative picture, place the object on the sensitive surface of the paper, and press thereon a piece of plate-glass, so that the object and paper may be in the closest possible contact.
7. Expose to day or sun light so long that the paper may acquire a dark mulberry tint in those places where the light has free access.
8. When the picture is finished, remove it at once into a dark room, and fix by means of a solution of hyposulphite of sodium.
9. Wash abundantly in cold water, so as to remove all trace of the salts. This should be done by placing the picture in a basin of water for some hours, and meanwhile frequently moving it in the liquid.
10. The picture may then be dried, and pasted or gummed on a piece of cardboard.
11. To obtain a positive picture from a negative, place the negative, face downwards, on a piece of sensitive paper, the two being pressed together by means of plate-glass, or otherwise. When the picture is finished, proceed as recommended in Nos. 8, 9, and 10.

If resident in any of our large towns, the operator may purchase paper which is ready salted, and also covered with albumen. This only requires to be excited by placing the albumenised side on the silver solution, as named in No. 4. This paper may be prepared by dissolving fifty grains of salt or sal-ammoniac in two ounces of water, to which twice as much of the clear white or albumen of an egg has been added. The mixture must be well shaken together, and then strained through muslin. The paper may then be laid on its surface after the manner before recommended for the salting process. The albumen gives a nice gloss to the picture, and so greatly improves its appearance.

We need scarcely state that an ingenious person may apply the above process to a vast variety of interesting and amusing purposes. Leaves of trees, flowers, ferns, engravings, lace patterns, and an immense number of similar subjects, may thus be easily copied; indeed, we know of no branch of scientific application so readily acquired, and more varied or interesting in its pursuit.

We may here mention that the ordinary process of marking linen by means of common

"marking-ink," and various modes of dyeing hair, are really but applications of photographic principles and practice. In most of these cases, solutions of the nitrate of silver are employed; and the results obtained are identical with those we have named, except so far as the objects to which they are applied are concerned.

Having thus attempted to introduce the reader to some of the most elementary instances of the practice of photography, we now proceed to describe more intricate processes, by means of which the highest class of effects are obtained; and which will of course require greater attention, care, and perseverance in their pursuit, than those to which we have hitherto referred.

Photographic Chemistry.

We have at a previous page shown that the science of photography may be divided into two branches, the physical and chemical. The former we have dealt with so far as the fundamentary laws of light are concerned; although we shall have to revert to, and expand on the subject when we have to deal with the apparatus, such as the camera, etc., used by the photographer. In regard to the chemical part of the subject an immense field of inquiry is laid open by the constantly increasing demands of the higher practice of the art. One of the most eminent practical photographers, now living, and who has made a handsome fortune by his pursuit of the art, owes all his success to a deep study of the laws of chemistry as affecting photography. From attention to these the art has made astonishing progress. In its early days a sitter for a likeness had to keep rigidly quiet and in the same position for a period of from ten to thirty seconds to ensure a successful photograph. Now nothing is easier, provided proper precautions be taken, than to photograph a cannon ball in its progress from the muzzle of the gun to the target, although the rate of its speed is generally 1,500 feet per second, or at the rate of about 1,000 miles per hour. This indeed may justly be called instantaneous photography.

As already stated, the business of the scientific photographer is to select such chemical compounds as will most speedily effect his object. Assuming that for most, if not all, purposes he chooses pure silver as the metal that forms the basis of his operations, it may be stated that three other elementary bodies combined with that metal, either individually or collectively, afford the means of rendering the metal suitable for his purpose. These three are *Chlorine, Iodine,* and *Bromine*, forming with silver the *chloride of silver*, the *iodide of silver*, and the *bromide* of that metal. All and each of these compounds are to a greater or less degree sensitive to the action of light.

We have just used a term that requires explanation: it is that of *Elementary.* The whole of the bodies we know in Nature may be divided in two great classes, *Elements* and *Compounds*, or *Compound bodies.* By the expression *Element* we mean not a body that is incapable of further decomposition, but one that has hitherto resisted all our attempts to decompose it; that is, to get from it any other body but itself.

Let us, for example, take a very simple instance, in the case of common salt. This is a compound, and, as already explained, contains two substances, chlorine and sodium. Now these two last-named are called *Elements,* or elementary bodies, because hitherto they have resisted all our attempts to resolve them into, or get from them, other substances. All compounds, salts, etc., etc., are therefore combinations of two or more elements. In the case of common salt we have only two elements; but in other instances four or more are combined. Thus the albumen or white of an egg, much used in photography, is composed of four elements, namely, hydrogen, oxygen, nitrogen, and carbon. Pure water, which was formerly considered an elementary body—one of the four, air, earth, fire, and water—is known to be a compound consisting of hydrogen and oxygen. Air is also a compound, as are all the earths. As to fire, we will leave that to its fate, but if by that term is meant heat, all we can say is, that we know nothing of it except by its effects, a condition which we have already pointed out in regard to light.

But an important point must be borne in mind by the photographer: it is that elementary bodies only combine with each other in *definite proportions.* This is a matter of the utmost importance to all who, like the photographer, have to make compounds. A knowledge of this law will prevent great waste, and, what is often worse, uncertain results. To the theoretical chemist it affords an insight into the probable atomic constitution of matter, enabling him to advance on grounds of probability and rational arguments, in a matter concerning which philosophers of antecedent ages have been guided by metaphysical speculations on the one side, and strained mathematical analogies on the other. To the practical chemist it affords a means, no less easy in application than unerring in its results, of learning the necessary quantities of substances to be used in his processes, and anticipating the quality and the quantity of his results.

As an example of the advantages conferred by an acquaintance with the laws of definite chemical proportionalism, we will cite one simple case, although in conducting the description it will be necessary to assume the knowledge of certain facts not yet treated of, concerning which the reader may probably be unacquainted.

It is a quality of sulphuric acid, in whatever soluble form existing, whether simple or in combination, to combine with the earth baryta, and to be precipitated in the form of sulphate of baryta—a most insoluble compound.

First, let the simple case be assumed that a certain liquid—perhaps water—contains a certain but small amount of sulphuric acid, which amount it is desired, by way of analysis, to separate. To evaporate away the water and leave the sulphuric acid, in the condition of one part acid to one of water (oil of vitriol of commerce), if possible at all, would at any rate be

exceedingly difficult, and would involve the necessity of an amount of delicacy in manipulation far too great for ordinary practice. Having confidence, however, in the law of chemical proportionality, and being aware that the combination of sulphuric acid with baryta is an insoluble body, the operator would proceed to throw in some of a solution containing baryta—nitrate of baryta for example—and he would continue the operation so long as any precipitate made its appearance; he would then dry his precipitate, weigh it, and referring to some list of chemical equivalents, for the purpose of ascertaining the proportional combination of sulphuric acid with baryta, would find that every 116 parts of sulphate of baryta contained 40 parts of sulphuric acid. On this principle of indirect demonstration are by far the greater number of analytical points determined.

As another illustration, let us take the chloride of silver, already often mentioned. It is a definite compound of silver and chlorine; that is, it invariably contains such quantities of each as always agree. Thus, it is composed of 36 parts of chlorine and 108 parts of silver to make 144 parts, grains, pounds, or even tons of chloride of silver. This proportion is invariable, for no matter how much of a solution of nitrate of silver is added to one of common salt, the proportions of the chlorine and the silver are constant.

There are many examples in which bodies unite in one proportion only; and in all such cases the proportion of the elements of a compound must be uniform for the species. Thus, hydrogen and chlorine unite in no other proportions than those constituting hydrochloric acid, which, by weight, are one of the former to thirty-five of the latter. Whatever of either ingredient is in excess, remains uncombined after the experiment. In cases of this sort, combination is generally energetic, and the characteristic qualities of the components are no longer observable in the compound. Chloride of silver affords an eminent instance of this kind; as also does common salt, which is composed of chlorine and the metal sodium. In common salt, both the chlorine and the sodium, would be fatal to life, while their compound, common salt, is generally considered as essential to our healthy existence.

Other bodies unite in several proportions; but these proportions are definite, and, in the intermediate ones, no combination ensues. Thus six parts, by weight, of carbon, combine with eight of oxygen, or with sixteen, but with no intermediate quantity; sixty-four parts of copper combine with eight of oxygen, or with sixteen, and with those proportions only. This law of *combination in definite proportions*, though deducible from the previous experiments of Wenzel, seems to have been first discovered and established by a series of researches undertaken with that view by Richter, of Berlin, and published between the years 1796 and 1798. The great object of that chemist was to determine the relative capacity of saturation of the acids and bases, and to represent them by a series of numbers, serving the same purpose as the Tables of Chemical Equivalents now constructed. It is unnecessary to copy the Table of Richter, because the results are, for the most part, inaccurate; but, notwithstanding this, the merit of the first conception of such a table unquestionably belongs to him. Prout afterwards contributed to establish the law, by showing that iron and antimony do not unite with oxygen in all proportions, but only in very few determinate ones; and, in a controversy with Berthollet, which was most ably and temperately conducted on both sides, he urged convincing arguments in favour of limited combinations.

This fact has led to the formation of a table of what are called *Chemical Equivalents*, giving the proportions in which elementary bodies unite. In the following such of the elementary bodies are named, out of about seventy, that the photographer has to deal with, and to which we shall have frequent occasion to refer in our future pages. The figures after each denote the equivalent, or, as it is sometimes called, but very improperly, the *Atomic Weight* of the element. The abbreviations are the symbols designating the elements, and these symbols we shall frequently use to save space. Thus the symbol and equivalent of chloride of silver will be written thus: Ag. Cl.=144, or of Nitric Acid $NO_5=54$, of common salt Na. Cl.=59, etc.

Bromine	Br. 80.
Cadmium	Cd. 56.
Calcium	Ca. 20.
Carbon	C. 6.
Chlorine	Cl. 35.
Chrome.	Cr. 26·7.
Copper	Cu. 31·7.
Fluorine . . .	F. 18·9.
Gold	Au. (Aurum) 197.
Hydrogen	H. 1.
Iodine	I. 127·1.
Iron.	Fe. 28.
Lead	Pb. 103·7.
Manganese . . .	Mn. 27·6.
Mercury	Hg. 100.
Nitrogen	N. 14.
Oxygen	O. 8.
Palladium . . .	Pd. 53·3
Phosphorus . . .	P. 32.
Platinum	Pt. 98·7.
Potassium. . . .	K. (Kalium) 39·2.
Silver	Ag. 108·1.
Sodium	Na. (Natrium) 23.
Sulphur	S. 16.
Tin	Sn. (Stannum) 59.
Uranium	U. 60.
Zinc	Zn. 32·6.

To one or more of three substances (chlorine, iodine, and bromine) the photographer, as already stated, is indebted for his most successful results. The following remarks will put the reader into possession of some of their chief characteristics:—

Chlorine.—Chlorine may be obtained in various ways. It is a constituent of common salt, etc.

Place a teaspoonful of chloride of lime (bleaching-powder) in a glass bottle or jar; pour on the powder a little hydrochloric (muriatic) acid and water; in a little time gas will be given off, and will gradually fill the jar. It has a greenish-yellow colour; hence the name, chlorine, from the Greek. Its smell is very penetrating; and if a piece of paper, coloured by litmus or any other vegetable, be dipped therein, it will be immediately bleached. Hence the employment of chloride of lime, in the manufacturing districts, for bleaching cotton and linen goods.

Iodine.—This element is obtained from sea-water, and was first discovered by its action on the pans in which common salt was evaporated. In its ordinary state, it is a dark-coloured powder. Heat a little of this on a plate, and observe the colour of the vapour, which will be of a rich purple; and thence has arisen the name of the substance. Combined with potassium or potass, it forms the iodide of potassium, or hydriodate of potass: names which are used for the same salt. Iodide of potassium is largely employed for a variety of purposes in photography.

Bromine.—This is always sold in a liquid state, and, like iodine, is obtained from sea-water. It has a deep orange colour, and most offensive smell. Expose a little of the liquid bromine to heat; its characteristic vapour will be at once noticed: the fumes, however, which are extremely irritating, should be avoided. Bromide of potassium—that is, bromine and potassium united together—is the combination most used. Bromine and iodine are used, together with collodion, in the liquid state for the collodion process; whilst, as vapour, they are employed for making the silver plates of the Daguerreotype process sensitive, before being placed in the camera.

We next turn to describe some of the most important substances that form compounds with the preceding, and other chemicals employed in the art.

Silver.—This metal is employed both in the metallic state and in the form of nitrate of silver: the former is used in plates for the Daguerreotype process, or as plating or covering a sheet of copper; and the salt is universally used in the calotype, the collodion, albumen, and other processes of photography generally.

The salt, nitrate of silver, is easily formed by putting a piece of pure silver in a little nitric acid diluted with water. A violent action takes place; the metal is dissolved; and by evaporating the solution, crystals of the salt are easily obtained. It, however, is far better that the operator should purchase the salt at a photographic chemist's or instrument-maker; as such prepare it more especially for photographic purposes, and thus avoid a variety of impurities which are ordinarily found in the nitrate of silver of commerce. It may perhaps be as well for us to remark, that all photographic chemicals, except liquids, may be procured by post from any of the leading towns in Great Britain and Ireland. This may be valuable information to those resident at a distance from such places. In our own journeys we have met with several "towns" so called, wherein we could not purchase a chemical of any kind; and while writing this, we have in our mind's eye two places in Scotland, containing each over two thousand inhabitants, wherein neither medical man or chemist and druggist could be met with, or could their professed wares be obtained at any price—a fact which unutterably astonished us, considering the prevalence of "medicinal taste" amongst us as a people.

On adding a substance containing chlorine, iodine, or bromine, to nitrate of silver, compounds are formed, being respectively the chloride, iodide, and bromide of that metal. The chloride of silver is a white powder, turning to a dark mulberry tint on being exposed to the action of light. The iodide of silver is of a yellow colour, as is also the bromide; each being produced on adding either the iodide or bromide of potassium to nitrate of silver. These compounds are formed when a plate, covered with iodised and bromised collodion, is dipped into a bath of nitrate of silver—a process into which we shall extensively enter when we consider and describe the usual method of taking likenesses, etc., by means of collodion, gelatine, etc.

In chlorine, iodine, bromine, and their salts, or salt-like combinations, we have described the chief active agents employed in photography; and in silver we have the substance acted on by them. The resulting products of their mutual action are the media which the photographer employs directly to obtain his result; but these have to be placed or used in combination with others. His chemicals are as the colours of the painter; whilst his collodion, etc., take the place of the painter's canvas.

Collodion and Gun-cotton.—Collodion, like its basis, gun-cotton, is of comparatively recent discovery; but it has done more to extend and render popular the pursuit of photography than any other invention which has been connected with the art; and the process deriving its name from the substance at once affords beautiful and satisfactory results. Whilst we urge on our readers the wisdom of purchasing, rather than of attempting to make their collodion, we shall give a general direction as to its manufacture, so that its composition, etc., may be fully understood; and to this end we describe the method by which gun-cotton may easily be made.

Put some perfectly clean jewellers' cotton, or cotton wool, into a glass jar, or a common tumbler. Mix in a porcelain vessel equal parts of strong sulphuric and the strongest nitric acid; and, after stirring these together, allow the mixture to cool. We name a *porcelain* instead of a glass vessel, because of the great heat produced, which would almost certainly destroy glass. The mixture should also be made in the open air, or in a place where a draught would carry off the suffocating fumes which are given off. When the acids have cooled, pour them on to the cotton wool, and press them together repeatedly for about five minutes by means of a glass rod, so that every part of the cotton may be well moistened with the acids. It then

should be removed by means of the glass rod, and washed under a tap of running water, until every vestige of acid is removed. This can be judged of by the taste of the water as it runs away. The cotton may then be pressed between a clean cloth; and afterwards being opened out, so as to expose plenty of surface to the air, it may be dried either in the sun or in a warm room. Artificial heat should only be used with great care, because an explosion might ensue if too great heat be applied. Blotting-paper, saw-dust, etc., may be treated in a similar manner, and they will undergo identical chemical changes.

If the cotton thus prepared be ignited, it will be found to explode suddenly like gunpowder, and not in the slow fashion that takes place when common cotton wool is placed in a flame. Indeed, the substance has been frequently employed instead of gunpowder for blasting purposes. It, however, undergoes too rapid a combustion to be of use in rifles, cannon, etc.; and is a dangerous agent if so employed, generally causing the bursting of the piece.

Having thus obtained the gun-cotton, or, as it is chemically termed, "pyroxyline," the next step is to dissolve it, and so to form collodion. This is done by adding a few grains of the cotton to a mixture of six parts of ether with three parts of alcohol, highly rectified; or the following proportions may be taken:—

Gun-cotton	10 grains.
Ether	half an ounce
Rectified alcohol. . .	quarter of an ounce.

These should be added together in a glass-stoppered bottle, and, after a short time, the greater portion of the gun-cotton will dissolve, and this solution will be collodion.

If a little of this solution be dropped on to a glass plate, the spirit will soon evaporate, and a fine film will form on its surface. It is this film that is employed to hold the chemical agents which are subsequently placed on its surface, and by whose changes, under the action of light, the photographer effects his beautiful results.

The collodion, thus prepared, requires, however, other additions to fit it for use; and these consist of substances which, by their action on the silver solution in which they are afterwards placed, render the coating sensitive. For this purpose, iodide of potassium, iodide of ammonium, or that of cadmium, may be added to the collodion. The iodising of the collodion is a question on which almost every operator differs; and it is, to a large extent, an empirical subject. We shall, therefore, state generally that the addition of a few grains of either of the three salts, iodide of potassium, ammonium, or cadmium, to the quantity of collodion manufactured as we have just directed, may be employed by the student. We still, however, only mention this that he may understand the constitution of iodised collodion; and, as before, advise its purchase as ready prepared. The uses and modifications of this liquid we shall fully consider hereafter.

We have thus dealt with most of the substances employed for the ordinary processes, so far as preparing the plate for the camera is concerned. We now proceed to speak of others which are employed for developing and fixing the pictures on the removal of the plate from the camera after its exposure to light, referring chiefly to those of the collodion process. Omitting alcohol and ether, we shall chiefly refer to those which are most in demand; and shall thus avoid distracting the attention of the operator by too extended a description.

The following acids and salts are variously employed for developing solutions; namely, acids—acetic, gallic, pyrogallic, and nitric; salts—protosulphate, and protonitrate of iron, etc. Acetic acid is the basis of the vinegar of household use; but for the purposes of the photographer, a pure and strong kind is required. It is generally sold by the photographic chemists, under the name of glacial acetic acid, which is its strongest state, and which will assume the solid form when at a temperature near the freezing-point of water.

Gallic acid is produced by the decomposition of gall-nuts, which are freely exposed for a few weeks to the action of the air and water. Pyrogallic acid is obtained by the action of heat on gallic acid; and is largely used in the collodion process; whilst gallic acid is equally so for the calotype.

Nitric acid is employed for various purposes as a photographic agent. Its usual source is nitre, whence it is obtained by distilling that salt with sulphuric acid and water. Hydrochloric or muriatic acid is similarly obtained by distilling common salt, water, and sulphuric acid together. But these and sulphuric acid should, when required in a pure state, be bought of the photographic chemist, as the act of freeing them from impurities is troublesome and also very difficult.

Iron Salts.—Protosulphate of iron is well known under the name of green copperas, although not a particle of copper enters into its composition. It is composed of iron and sulphuric acid, and may be obtained by adding these together. In a pure state it is sold in the form of rich green crystals, and is much employed for developing solution. Protonitrate of iron, which is also similarly used, is composed of iron and nitric acid, and may be made by mixing together a solution of sulphate of iron, and one of nitrate of baryta. For making small quantities of this salt in solution, 100 grains of each salt should be dissolved in water in separate vessels. On the two solutions being mixed, a white powder, the sulphate of baryta, will fall down; and being filtered from this, the solution will contain the protonitrate of iron.

Hyposulphite of Soda.—Having thus disposed of those acids and salts mostly employed in the collodion process, we conclude by referring to two substances used for the purpose of fixing the picture, or, in other words, to remove the unchanged salts of silver, and so to prevent any further chemical change being produced on its subsequent exposure to light. Hyposulphite of soda is largely prepared for photographic "fixing," and is accordingly a cheap and easily

procured salt. The strength of solution required will be mentioned when we further refer to its use. It is obtained by transmitting sulphurous acid through a solution of carbonate of soda. Sulphurous acid is a product of the combustion of sulphur, and may be abundantly obtained by heating sulphuric acid with the metal mercury in a glass retort.

Cyanide of Potassium.—This salt has lately come into great use as a fixing agent, and is also largely employed in electro-plating and gilding. It is generally procured by heating together, in fine powder, one part of dry carbonate of potass with two parts of ferrocyanide of potassium (yellow prussiate of potass): a white deliquescent powder is the result. We may here warn the student, that this salt is a most deadly poison, owing to the presence in it of cyanogen (the base of prussic acid); and he will act wisely in avoiding the smell which arises from its solution: he should also be cautious in immersing the hands, especially if they are at all wounded, or the skin abraded. This salt should be kept in close-stoppered bottles, as it readily absorbs moisture from the air.

Such are the chief chemicals, with the exception of gold solution (which should always be purchased) that are employed by the photographer. But we should leave the subject incomplete if we did not make a few remarks on certainly the most important agent of the art—we mean water.

While water is perhaps the most abundant of all the products of nature, *absolutely pure water* is one of its greatest rarities. Few, even chemists, have ever seen or tasted it in anything like quantity. It can only be prepared by igniting oxygen and hydrogen in the proportion of one of the latter to eight of the former in platina vessels, and even as a curiosity we have never seen this done. Common water has invariably foreign substances dissolved in it, such as salt, sulphate and carbonate of lime, with other mineral and organic impurities.

It is necessary, therefore, that the photographer should employ only distilled water. If he were to attempt to dissolve nitrate of silver in the water ordinarily supplied for domestic purposes, he would find that the solution would soon appear milky, and that the white curdy powder formed—the chloride of silver—from the common salt in the water, would become blackened by light. Other salts would be similarly affected. Even the common air contained, together with carbonic acid, in ordinary water is also objectionable. Distilled water may be purchased, but it can rarely be depended on. It is, therefore, very desirable, where much water is used, for the photographer to distil it himself. An ordinary tea-kettle, with a few feet of pewter pipe fixed to the spout, might do, but the water is apt to boil over and run down the pipe, and so the operation is spoilt. When required in but small quantities, it can be made by using a pint-glass retort, supported on a ring-stand. A spirit-lamp may be employed as a source of heat; and the stem of the retort should be kept cool by means of wet cloths, as shown in Fig. 324.

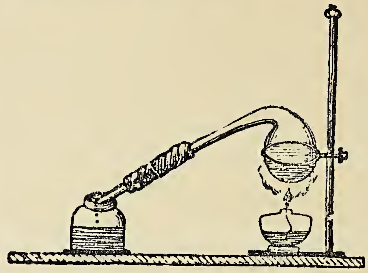


Fig. 324.

The distilled water thus obtained, if care be taken, is very pure, but can only be obtained in very small quantities. A larger piece of apparatus is therefore required where much distilled water is used.

A useful still may easily be constructed by an intelligent smith; and such as is represented in Fig. 325 is a convenient form.

A is the body of the still, into which the water to be distilled is introduced. Round this vessel the fire is placed. B is the head of the still, through which the vapour passes by means of *c*, until it arrives at *d*. *d* is the worm, surrounded by cold water. In this part the steam is condensed, and escapes, as distilled water, at the tap *s*, where it may be collected in bottles, which should be kept carefully corked.

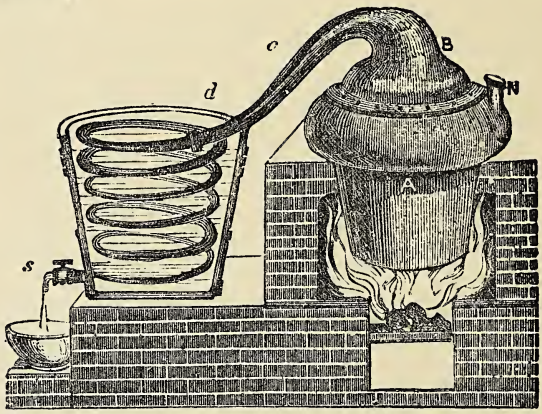


Fig. 325.—Water-distilling Apparatus.

The form of distillatory apparatus known as the still and worm is very little employed in chemical laboratories of research, except for the purpose of distilling water; it almost exclusively belongs to the department of manufacturing chemistry. The various necessities involved in the course of distillatory operations require numerous kinds of apparatus for effecting condensation. For general purposes, however, the

condenser known as *Liebig's* is unquestionably the best, and therefore merits a special description. It is constructed as follows :—

Procure a tube of brass, copper, or tinplate, of about two and a-half inches in diameter, and not less than two feet long. Occlude either end of the metallic tube with an accurately-fitting bung, rendering the juncture between the cork and the metal water-tight by some appropriate lute. To this end there is nothing better than a

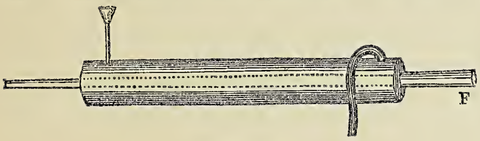


Fig. 326.

stiff paste of white lead ground in oil, but, as it is rather long in drying, a lining of sealing-wax may be substituted for that end of the tube which will be furthest removed from the retort, flask, or other distillatory vessel, and which will therefore be the cooler of the two.

The next step in the manufacture of Liebig's apparatus consists in boring two lateral holes in the metal tub, one near either extremity. Into each of these holes solder a piece of gas-pipe about eight inches long ; bend one of these pieces into the form of a syphon, and solder to the extremity of the other a small tin-plate funnel. It now only remains to perforate both corks, and to thrust securely through the perforations a length of glass tube, somewhat funnel-shaped at one extremity, and the apparatus is complete. The functions of this elegant condenser will be readily understood by referring to the following diagram, which shows it mounted in connection with a distillatory retort and a receiving vessel.

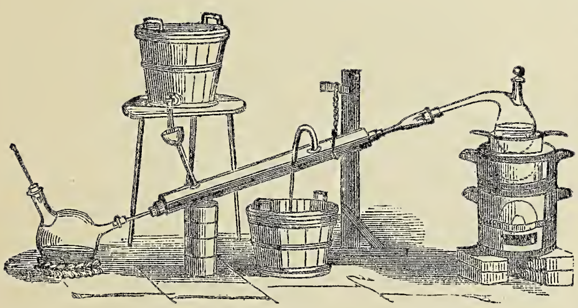


Fig. 327.—Liebig's Still.

Every theoretical condition for obtaining the maximum cooling effect of water is here applied by the most simple means. Inasmuch as the most elevated extremity of the metallic tube contains the hottest water, the final departure of that liquid should take place from the point in question. It *does* so, as the student will perceive, through the syphon-like termination ; and a continuous stream of cold water is supplied at the lower extremity of the apparatus through the little tin-plate funnel.

Photographic Apparatus.

Before proceeding to detail the various processes now in use, we shall enter into a description of the apparatus which will be required by the operator.

The chief photographic instrument is the camera. A camera of an ordinary kind, suitable for a beginner, may be procured for a moderate sum ; but where the means of the student will permit, none but the best kind, as to construction and character of the lenses, should be employed. Many persons commencing the practice of photography, are content to do so with an inferior instrument. Having thus to contend with difficulties which, from their want of knowledge of the science of optics, they can neither overcome nor control, they often entirely fail in obtaining good results, and, consequently, are soon discouraged by failure. The following remarks on aberration will at once suggest to the intelligent reader, that the construction of an accurate camera depends on an extended acquaintance with the law of optics, combined with a high degree of skill on the part of the maker ; and of course such acquirements both demand and deserve an adequate pecuniary recompense; hence the high price of some cameras employed in the art. If a lens could be ground of such an exact shape as to overcome the occurrence of spherical aberration, as easily as the difficulty of chromatic aberration has been dealt with, such would, of course, almost arrive at perfection. We here observe how exact are the works of the Deity compared to the best productions of human skill. In the eye we have every change of circumstance at once provided for, as each of its parts is exactly adapted for that end or purpose. Now, the lens of the camera has to fulfil the same object as the crystalline lens of the eye ; and to extend our analogy, we may add, that the prepared plate of the photographer is the analogue of the retina of the eye; for, like it, it has to receive and communicate impressions of the rays of light incident on its surface.

Lenses.—The theory of lenses directly follows from the operation of the law of refraction of light, as will be recognised after inspecting the following diagram. The simplest mode of seeing clearly the rationale of a lens consists in regarding it, firstly, as having its curves made up of as many small tangent planes as there are rays of light from a luminous body,—that is to say, an infinite number of such planes ; secondly, in regarding these planes to be reduced, for the sake of easy comprehension, to a small number. In this diagram, the plano-convex lens, A, has been reduced in B to a conventional form, for the sake of exemplification. *a b c*

represent three parallel rays of light, each falling on its own plane, going through the lens, and finally converging on the focus *d*. On observing the directive tendency of these rays, with reference to the perpendiculars, *e e*, *p p*, it will be seen that the law is satisfied, and that the natural result of thus satisfying the law is the convergence of the rays *a b c* into a focus. Whatever be the form of a lens, the same law holds good.

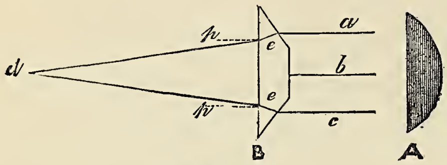


Fig. 328.

Spherical Aberration.—Convex lenses, which are segments of spheres, such as the lens No. 1, and those concave lenses, which may be described as planes from which spherical segments have been excavated, may be termed spherical lenses. Such lenses possess the defect of scattering certain rays even of mono-chromatic light from the true theoretical focus, and producing an indistinct image. This defect is termed spherical aberration. It takes place altogether near the edges of such lenses, and may, therefore, be obviated by means of a curtain, or stop, similar in its nature to the iris of the eye, with its central pupil, although at the expense of a certain amount of illuminative power.

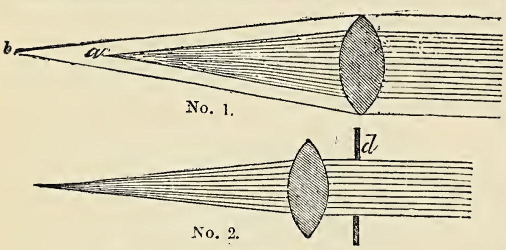


Fig. 329.—Aberration of Lenses.

In No. 1 this spherical aberration is represented. The greater number of rays fall, as they ought to do, on the theoretical focus *a*; but a few wander from that point to *b*, and constitute spherical aberration. It will be evident that a diaphragm, or stop, with a central orifice, as represented in section by *d*, will have the effect of cutting off these wandering rays.

The rationale of the peculiar effect which the edges of spherical lenses have in developing spherical aberration, is too purely optical in its character for discussion in this place.

Descartes applied himself to the task of obviating spherical aberration by varying the form of lenses from sections of spheres to sections of certain ovals, which, from the name of Descartes, are termed the Cartesian ovals. He thus succeeded in obviating the defect for any one kind of homogeneous light. In his time the circumstance of the compound nature of white light was not known. Further experience demonstrated that each colour of light possessed its own refractive power; consequently it followed that no lens, however varied as to shape, could be free from spherical aberration as regards white or compound light; or, more properly speaking, what would have been mere spherical aberration with a common spherical lens, became chromatic aberration with a lens formed on the basis of a Cartesian oval.

Chromatic Aberration.—Spherical aberration, we have seen, may take place when monochromatic light is employed; but chromatic aberration necessarily presupposes the employment of compound or white light, and is developed like mere spherical aberration by the effect of the edges of spherical lenses on light passing through them.

The rationale of this agency will be easily understood on reflecting that the edges of a lens approach to the character of a triangular prism, the two sides of which adjacent to the edge have been bent into curvilinear forms. The fact, moreover, will be anticipated, that this kind of aberration may be greatly obviated by means of a curtain, iris, or stop. Nevertheless, it is not possible by this means alone to render optical instruments achromatic; and had the optician no better method of obviating the defect than by a stop, refracting telescopes must have remained in the imperfect condition of the time of Sir Isaac Newton; displaying white objects not in their true colour, but surrounded with an iris-like fringe. Newton proclaimed the idea of making achromatic refracting telescopes to be hopeless; nevertheless, it has been fulfilled by a means no less simple than beautiful — the compound lens, the principle of which is as follows :—

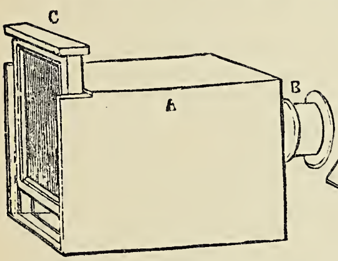
Different kinds of glass possess different refractive powers for the same colour of light. Thus, if a glass which may be endowed with the property of refracting yellow and red light by one degree more than blue, be combined with another which has the exactly opposite property of refracting blue by one degree more than yellow and red, then it should theoretically follow that the resulting action of two such glasses should be a perfect compensation. This indeed is found practically to be the case. Perfectly achromatic lenses are now formed of compound glasses placed in apposition; and the achromatic telescope spoken of by the illustrious Newton so despondingly is now amongst the best known and most common of optical instruments.

It will thus be seen that in the most important department of the photographic art great difficulty is experienced by the instrument-maker, but to a large measure such difficulties have been overcome, and lenses of an almost perfect character have been produced.

It would, of course, be highly improper for us to recommend any instrument-maker, in preference to others, of whom the student might purchase his camera, and other photographic apparatus. We, however, shall attempt to explain the advantages and improvements which

have been introduced by various persons; and giving the student an opportunity of judging of the essential points to which his attention should be directed, we must leave to his own judgment and preference the particular form, etc., of the instruments he may desire to obtain. Two classes of cameras, or at least two sets of lenses for the camera, are necessary, for the separate purposes of taking likenesses and landscape views. This will be evident when it is remembered that, in the first instance, the object may be placed close to the instrument; whereas, when taking a photograph of a country scene, etc., the different objects will be at all possible distances from the centre of the lens. The human eye is capable of adapting itself instantaneously to the variations of distance in respect to objects seen by it; and to a certain, but not entire extent, the same result is effected in the position of the lenses of a camera by a mechanical arrangement—the operation being termed "*focussing.*"

In the annexed engraving, the general arrangement of the photographic camera is represented. In Fig. 330, A represents the box of the camera; B a brass tube in which the lenses are placed;



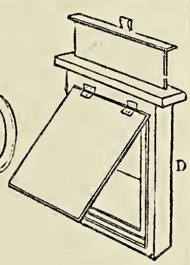


Fig. 330.—Photographic Camera. Fig. 331.

C a slide or dark frame, in which the sensitive plate is fixed. In Fig. 331, D shows this frame in its details; the back being opened, so that its internal construction may be observed.

The image received on the ground-glass plate at C, in Fig. 330, is focussed in this form of camera, by moving or adjusting the lens contained in the tube B in front of the camera; hence its use will be necessarily confined to occasions wherein such limited adjustment is admissible or required. Another form of the camera, in which the distance between the ground-glass plate for viewing the image, and the tube in which the lenses are placed, is illustrated in the following engraving.

In Fig. 332 we observe that the box of the camera is divided into two parts, of which B is so constructed as to slide easily in and out of A. Thus the ground-glass plate represented in the frame D, may be extended to and fro from the lens, and a greater focal arrangement can be arrived at.

A very convenient form of camera, for travelling purposes, is represented in Fig. 333. The body of the box, instead of being solid, is made exactly like the bellows of the concertina. The back, *c*, holding the plate, can thus, by means of the folding construction of *b*, be easily shifted any distance from *a*, the part of the arrangement holding the lenses; and all parts are maintained in a firm condition, when in use, by means

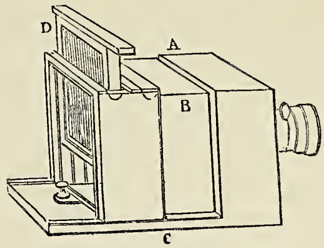


Fig. 332.

of the cross-bars *d d*. These are secured in any desired position by means of screws working through slots in the bars.

We need not, however, occupy further space by details of those forms of the camera which result from the peculiar choice, requirements, or means of the operator. Any, or most of these,

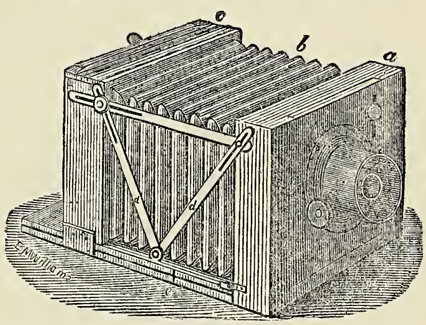


Fig. 333.—Folding Camera.

may be inspected at the optical instrument-makers, who, according to their individual opinions on the subject, will be able to give more precise and effective descriptions than it falls to our province to attempt. We may, however, offer a word of advice to those who may be desirous of purchasing an instrument; and, in so doing, we need scarcely state, that the purchaser will do wisely to seek his apparatus only at a house whose reputation for skill and respectability is well attested. Achromatic and properly ground lenses, their transparency, firmness of workmanship in the material of the box, are the essential points. We have seen cameras made of unseasoned material, in which some of the parts of the woodwork have contracted by change

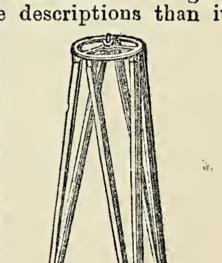


Fig. 334.

of weather, which render them extremely inconvenient, not to say useless. In such cases, the dark frame, by fitting too tightly or loosely in the slide receiving it, will often cause the camera to be shifted whilst introducing the sensitive plate, and so entirely remove the camera itself out of position, and destroy the focus. We can only add, " *caveat emptor.*"

The camera requires a steady support, and one which can be adapted so that it may be placed in any position. One of the most convenient of these is that represented in Fig. 334; and one of this kind is equally available for house and out-of-door use. Great care should be observed in purchasing or making a stand of any shape, because the use of unseasoned wood soon causes them to become unsteady, and makes them utterly valueless.

Amongst the minor, but essential, apparatus of the photographer, are the following:—

Fig. 335 represents the dipping-bath, and frame for holding the plate in the silver solution contained in the bath.

Fig. 336 is a representation of a copying frame, by means of which positive copies are obtained from negative pictures. It is an im-

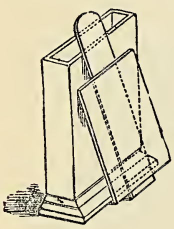


Fig. 335.
Dipping Bath.

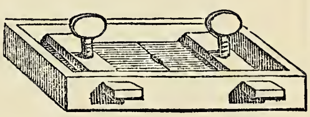


Fig. 336.
Copying Frame.

provement on the simple arrangement of the child's transparent slate, to which, and its use, we have previously alluded.

We have thus referred to some of the most essential arrangements required by the reader when commencing the study of photography. We shall allude to, and illustrate, various contrivances which have been invented for the purpose of facilitating several operations, as we proceed.

In our humble opinion, it is better that every student of science, whatever his means may be, should commence with as few "assistants" as is consistent with his progress. He is thus thrown on his own resources; he sees his wants; his ingenuity is stimulated to supply them; and his progress is infinitely more satisfactory to himself, and advantageous to others in every department of scientific research, than when he is helped over every little obstacle that may drop across his path. Both morally and mentally, "he that chiefly owes himself unto himself, is the substantial man."

Besides the different apparatus we have described, the tyro will require some glass-stoppered bottles of about four ounces capacity; square dishes of glass or porcelain for holding developing solutions, etc.; two or three graduated glass measures, each of eight ounces, of two ounces, one ounce, and one drachm capacity; some glass rods for stirrers; and a dozen or so of test-glasses, which, however, may be replaced by ordinary uncut wine or ale-glasses. He should also possess a spirit-lamp, of four or eight ounce size, and a small ring-stand, for supporting glass vessels in preparing solutions by heat; some glass funnels for filtering solutions, etc.; some filtering papers, or, what is nearly as good, some stout white blotting-paper; and last, and by no means the least of his requirements, is that of an unlimited supply of clean, soft towels, and of rain or soft river water for washing purposes. The question of distilled water for dissolving the chemicals, etc., we have already disposed of at p. 632, *ante*.

Photographic Processes.

In dealing with the numerous processes that have been employed in the art of photography a difficulty is where to begin; to end their description is impossible, inasmuch as new methods or improvements on those already known are constantly being brought out. The first process that was introduced into this kingdom for taking likenesses was that of M. Daguerre. In fact we owe to him the first steps which were taken to render practically useful the fact that salts of silver are applicable to retain the impression of solar influences. It is true that Sir Humphry Davy and Mr. Wedgwood, as already stated, were well aware that copies of objects might be obtained by the agency of light; but those eminent men never proceeded beyond the threshold of their discoveries. M. Niepce and M. Daguerre, however, applied themselves to the subject; and the result has been, that every part of the civilised world has become familiar with the fact that light may be made a most valuable servant.

About forty years ago, M. Daguerre discovered that plates of silver, coated with iodine, were sensitive to the action of light, and that those portions so acted on might afford a surface on which distinct pictures could be procured. This discovery produced a profound sensation in scientific circles; and the French government were so impressed with the novelty and value of the process, that they rewarded its discoverer in the most handsome manner. He had voted to him a pension of 6,000 francs; and France took to herself the credit of having given to the world one of the most surprising of discoveries.

That portion of the world which forms our native land, seems, however, to have been an exception; for a patent was taken out in this country, by which the employment of Daguerre's process was limited to one person and his licensees. If we compare the likenesses taken in the year 1840 with those of the present day, we shall certainly find that we hold the palm in every respect. This fact, however, must not deter us from doing justice to the valuable discoveries made by M. Daguerre.

One great objection which exists against this process is, that portraits, etc., produced by it, can only be viewed in one light, owing to the reflection from the silver surface. This is a source of considerable inconvenience, and, indeed, prevents any chance of representing some objects successfully.

We now proceed to detail each part of the process. In doing so, we shall not be so minute in our description as when speaking of the collodion process; in fact, the following description of the Daguerreotype is solely given as a matter of history, as the process has long been disused. The largest collection of Daguerreotypes we have seen was a series of about eighty, representing the ruins of Pompeii. These belonged to Mr. Condie, of Glasgow, and were unfortunately destroyed by the fire which took place in the Polytechnic Institution of Glasgow, in 1857. We may conveniently consider, separately, the following particulars, in the order in which we have arranged them:—

1. Cleaning the silver plate.
2. Iodising it, and exposing it to bromine vapour, etc.
3. Exposure in the camera.
4. The mercury process.
5. The fixing process.
6. The toning process.

1. *Cleaning the Silver Plate.*—We may here observe, that various sorts of plates may be employed, providing a surface of pure silver is formed thereon. Hence, copper, plated with silver by the ordinary method, or by electrotyping pure silver plates, or standard silver electrotyped over with pure silver, may be employed. In either case the surface requires to be highly polished; and the directions which have been given to secure this desirable result are innumerable. We presume that a perfectly level plate has been chosen, free from scratches, etc. Its surface should first be roughly cleaned from oxide by dipping it into, or by rubbing it over, with very dilute nitric acid; this removes a thin coat of the silver, but ensures, at the same time, more chance of success in the process of cleaning. The plate is then to be washed in plenty of cold water, so as to remove all trace of acid. This being effected, it may be polished by the following means:—Place the plate on a sheet of clean white paper, much larger than itself, and, by means of a pellet of the best cotton wool, which has been previously dipped in some of the best olive oil, commence rubbing the plate in a circular manner, from the centre to its outside. Having done this until the surface is covered with oil, dust over it some of the finest tripoli, and pursue the same plan of rubbing circularly, from the centre to the outside, for some little time. By such means all the coarse irregularities will be removed, and a tolerably level surface will be obtained.

The plan which we have adopted, after having given the plate the rough polish, is to wash it carefully with a mixture of equal parts of spirits of wine and liquid ammonia: this has the effect of dissolving and clearing away the minute portions of oil which would otherwise remain in the fine lines left on the surface of the plate; which, although invisible to the naked eye, may easily be detected by means of a microscope. After thus having cleansed the plate, it is to be held over the flame of a spirit or gas-lamp, which has the effect of driving away a thin film of air which always rests on polished surfaces. Some operators follow the plan of burning, that is, of holding the silver plate over the flame of a spirit-lamp until all trace of oil is removed. But this is a delicate operation. If carried too far, or not far enough, the picture will be certainly damaged.

A little clean cotton wool, made into a pellet, is then to be moistened with spirits of wine. Having dipped it into some of the finest tripoli powder, the plate is to be rubbed with it until a dark, jet-like appearance is produced: a dry pellet of cotton is then to be employed, to remove all trace of the powder. The last operation is that of buffing, or rubbing the plate on some velvet fixed tightly over a piece of wood. This is generally made, in shape and appearance, like a razor strop; and the plate is to be briskly moved, under pressure, to and fro on the surface of the velvet. By these means a brilliant polish is obtained; and, practically speaking, we may suppose the plate as fit for all subsequent processes. In large establishments, the surface of friction was frequently a circular buffer, revolving vertically, against the flat side of which the plates were pressed. The last stage of the use of the buffer, which must be done by hand, is that which is technically termed laying the grain, which consists of rubbing the surface of the plate in one direction, by means of a buffer, somewhat resembling an ordinary brush in shape.

We must here warn the tyro against carelessness in respect to the cotton wool, tripoli, and buffer, each of which is liable to catch small portions of dust, sand, or grit. Neglect of this is sure to afford a scratched and uneven surface on the plate. The smallest particle of any hard substance, repeatedly rubbed on a comparatively soft body like silver, produces an infinity of fine lines, and renders the plate useless. Our remarks on cleanliness, in a former page, have an equal application to the Daguerreotype process; and, indeed, too much care cannot be bestowed at each step of our progress. In the choice of the cotton wool, the best so-called jewellers' cotton should be used, as it is free from specks, dirt, sand, etc. The so-called medicated cotton, sold by the chemist and druggist, possesses similar advantages.

When the operator has a lathe in his possession, much labour is saved by its use in the operation of polishing Daguerreotype plates, because both buffer and plate may readily be fitted in it. The action is much more regular than that obtained by manual labour, and there is less risk of producing a scratched surface through over-pressure on any part. We need scarcely add, that the time required for polishing the plate is also materially lessened.

2. *Iodising the Plate.*—After thus producing a clean and polished surface on the plate, it must

then be made sensitive to the action of light by means of the vapour of iodine and bromine. In the earlier days of photography, iodine alone was employed; but the addition of bromine has many advantages, as we shall presently see.

The philosophical instrument-makers used to sell boxes expressly made for the iodising process. The student, however, will succeed very well by employing a square box of about four inches deep, and a little longer and broader than the plate. The latter should be fixed in a frame so that it may be exposed with the silver face downwards. The frame itself may form the lid of the box. In the bottom of the box a glass tray must be placed, to hold the iodine, etc. A similar box will be required for the bromising process, if the operations are carried on separately. Of this, however, we shall speak more fully as we proceed.

To iodise the plate, put a small portion of iodine into the glass tray at the bottom of the box just described, and having fitted the silver plate, face outwards, in the frame, place it horizontally over the tray containing the iodine. The vapour which arises will reach the silver surface, forming an iodide of silver, which should be of a rose colour. The time required to effect this varies according to temperature and other circumstances; and so, like many other photographic processes, must be left to the judgment of the operator. As soon as the rose tint is obtained, the plate may then have its sensitiveness increased by means of the vapour of bromine, etc.; and such have been termed accelerators, from their power of rendering the subsequent processes more rapid of execution. After being iodised, the plate becomes sensitive to the action of light, but not to any great extent. It is, however, desirable that iodising should be carried on in the dark room; whilst it is essential that the accelerating process should be so conducted. Great care should be taken that as little as possible of the vapour of iodine and bromine should escape into the room, because such not only may have a generally prejudicial action on the plates, but also on various metals, chemicals, etc.; besides the personal inconvenience and injury which might occur to the operator.

The accelerating effect is produced by exposing the plate, previously iodised, in another box, which has a glass tray, into which the accelerating solution is to be poured. The exposure is conducted in precisely the same manner as in the process of iodising, and a rich, but fuller, dark rose-red surface is obtained on the silver plate, which will then be nearly ready for exposure in the camera.

Accelerating Solutions.—A solution of bromine in water may be employed for this purpose; and it is made by adding some bromine to distilled water, and shaking the two together until as much bromine as possible has been taken up. One pint of this saturated solution is to be diluted with distilled water, until it presents a pale straw colour; and then poured, to the depth of half an inch, in the glass tray.

Another solution may be prepared by adding a few drops of hydrochloric acid to a drachm of bromine, which is then to be diluted with six ounces of distilled water.

By using the above solutions as accelerators, a rich red rose-colour is produced on the plate. The latter must afterwards be exposed again to the iodine vapour, until the silver acquires a very deep rose-red, or, occasionally, a blue colour, resembling that produced on steel when it has been heated to a temperature of between 600 and 700 degrees Fah.; and the iodising process is then finished.

An accelerator recommended by M. Claudet, has the advantage of preventing the necessity of a second exposure to the iodine vapour. A portion of it is poured into the glass tray of the accelerating box, and after the silver has been exposed to the action of the vapour for several minutes (even to the extent of half-an-hour occasionally), it is ready for the camera. The mixture consists of a saturated solution of iodine in bromine; which is easily done by adding as much iodine to the liquid bromine as it will take up. A bromide of iodine is thus formed, and as much of it is added to distilled water as will impart to the latter a full yellow colour. It is stated that this plan is always to be depended upon; and it has one advantage for the tyro—which is, that he can scarcely err in its employment.

We must here point out a few matters by way of caution. The iodine should be spread evenly on the glass tray; because, wherever it is in masses, it will produce a deeper tint over that part. Care must be taken not to disturb the particles of iodine by hastily placing the plate on the top of the box, as this might possibly cause the air inside to be disturbed, and so drive particles on to the surface of the plate.

The following method has also been recommended:—

First make a saturated aqueous solution of bromine, by dropping some of this body into water, agitating, allowing subsidence to take place, and finally decanting all the water which remains floating above the yet undissolved bromine. One part of this solution added to forty parts of distilled water constitutes the bromine water, of which the vapour is employed, by exposing the already iodised plate to it in a vessel similar to that already employed in the iodising process. According to Mr. Bingham, there is a corresponding tint with bromine vapour for every tint already developed with iodine, and at which the maximum amount of successful effect will be developed. A tabular view of these tints was drawn up by that gentleman, and which is here appended.

1st Iodine.	Bromine.	2nd Iodine.
Straw Colour.	Yellow.	Full Yellow.
Light Yellow.	Golden Yellow.	Rose.
Golden Yellow.	Light Rose.	Deep Rose.
Blood Red.	Damask Rose.	Light Blue.
Damask Rose.	Deep Rose.	Blue.
Deep Rose.	Light Blue.	Indication of 2nd Yellow.

This table is drawn up in anticipation of the third process of development, already mentioned, and which consists in submitting the plate once more to the agency of iodine vapour.

The preceding table will be of service to one commencing to practice the Daguerreotype from motives of curiosity; but as the eyes of each individual vary from another in estimating different tones of various colours, especially when the variety consists of only one colour, as a basis, much judgment must be exercised by the operator. A similar difficulty arises in estimating the candle value of a gas-light, two individuals often varying in their estimate of the light-power, although using simultaneously the same photometer.

3. *Exposure in the Camera.*—A sensitive plate having been produced, the next step is its exposure in the camera. The plate is carefully removed in a dark box to its proper position in the camera, precautions as to which we shall specially mention when describing the collodion process at a future page. The time of exposure varies according to a number of circumstances, each of which, as it presents itself, becomes the subject of annoyance to the operator, but yet adds to his knowledge and experience. We may, however, remark, that great care is required to prevent the effect called *solarisation,* which is due to over-exposure. This entirely destroys the contrast of light and shade, on which depends the beauty of all photographed productions. However, to prevent this, the operator must be well acquainted with the power of his lens, and the excellency of the plates and chemicals; matters which, of course, can only be gained by practice and experience.

4. *The Mercury Process.*—On removing the plate in a dark box from the camera into the dark room, no picture will be observed on its surface; it must therefore be exposed to the vapour of mercury, which, settling on the face of the plate, rests on those parts which have been affected by the action of light. For this purpose a peculiarly-shaped box is employed. In the lower part of it is a cistern, containing about two ounces of quicksilver; and in this the bulb of a thermometer is placed, which indicates the temperature of the mercury when heated by means of a spirit-lamp placed beneath it. This temperature should never be allowed to rise beyond 150° or 160° Fah. The plate is placed at an angle of 45° at the top of the box.

Presuming that a plate has been duly exposed to light, and is allowed to receive the vapour of mercury in the manner we have explained, we shall soon perceive that the parts which have been chiefly acted on by light are most deeply brought out by the mercurial vapour, and every other part receives its due proportion, and produces a corresponding effect.

By these means the latent picture becomes developed; the effects of light and shade are produced on the surface of the plate, and a representation of the object copied is afforded, correct and brilliant, just in proportion to the care which has been exercised by the operator in each process.

5. *Fixing the Picture.*—The next part of the process is that of fixing the picture, and of so preventing the further action of light on the plate. The only thing required is to remove the remainder of the sensitive silver compound from the face of the plate; and this is effected by immersing the latter, when cool, in a solution of one part of hyposulphite of soda, to from six to ten parts of water. It should be left in the solution for a few minutes, and then must be abundantly washed with cold water. This is best effected by allowing a gentle stream, from a water-tap, to impinge on the plate: by these means all the soluble salts are completely removed. As, however, common water contains lime, etc., the plate should be finally washed with distilled water; and it may then be dried by holding it at some distance over the flame of a spirit-lamp. In drying, great care should be taken that no drops of water are left on the surface, as they would be sure to form spots. As the plate heats, the water has a tendency to run off from its surface; and an attentive operator will take advantage of this fact, so as to prevent the occurrence of specks, etc., thereon.

The appearance of all Daguerreotypes is remarkably improved by submitting them to the action of chloride of gold, after they are removed from the hypo bath. The contrast of light and shade is thereby greatly enhanced, and the brilliancy of the picture is of course increased. The process is very simple, and may be performed as follows:—

6. *The Toning Process.*—After washing the plate, place it on a ring-stand, so that it may be quite level; and there is to be poured on it the following toning mixture, so that every part of the picture may be well covered. It is made as follows:—

Chloride of gold . . .	8 grains.
Distilled water . . .	4 ounces.

The salt of gold, having been dissolved, is then added to the following solution of—

Hyposulphite of soda .	25 grains.
Distilled water . . .	4 ounces.

The two solutions, when mixed together, have a slight yellow tint, which, however, passes off. Some of this being poured on the picture, the heat of a spirit-lamp is cautiously applied beneath each part, until minute bubbles appear. In a short time, the improving effect of the toning process becomes visible, in the intensity and depth of contrast produced between the light and dark parts of the picture. The plate may now be left to cool, and the gold solution is then to be washed off, by means of distilled water, until the plate is perfectly cleansed. The spirit-lamp may now be used to dry it; and on this being carefully performed, the whole process may be considered as complete.

We have thus given a detailed account of the successive processes which enable us to obtain pictures on silver plates by means of the Daguerreotype process; but have omitted numerous modifications and improvements which have been from time to time suggested by various operators, because, as already stated, the process

is becoming obsolete, in consequence of the greater value of, and the better results afforded by, the various processes on glass. It requires a considerable amount of care, and some photographic experience, to obtain even tolerable results; and, as we before remarked, the silver plate has the great objection of reflecting light, so that the pictures can only be seen at a certain angle. We are not aware of any photographer who professes to take portraits by this process at the present time; and therefore we have introduced the subject more as a curiosity, and as an illustration of the earlier attempts at picture-taking by the agency of light, than as one of any utility or profit to the experimenter.

We may conclude by stating, that if any of our readers attempt the process, and arrive at the very common result of obtaining "spoilt plates," such may be employed again by heating the surface to remove the mercury, and then by repeating the process of cleaning, according to the directions already given.

In our early photographic studies, the next process that presented itself was that of the Calotype, which, like the Daguerreotype, has also become nearly obsolete. We therefore next take it for description.

The Calotype Process.

One of the most ardent and successful of all those who early devoted their attention to photographic investigations, was Mr. Fox Talbot. From the commencement of the art he continually made contributions to our stock of information; and to him we are indebted for a great variety of improvements on the processes proposed by other experimenters.

So early as the year 1839, Mr. Talbot communicated his views to the Royal Society, in reference to "the art of photogenic drawing, or the process by which natural objects may be made to delineate themselves without the aid of the artist's pencil." He also pointed out how such impressions might be fixed or rendered unchangeable by the further action of light.

The earlier attempts at producing and retaining photographic copies were but of a comparatively valueless character. The numerous causes of failure to which we have already so fully alluded, were only distantly guessed at; and the eagerness with which each new discovery was hailed, frequently prevented that close and philosophic examination into the chain of circumstances which gave them birth, or into the causes of failure, which almost invariably produced disappointment in those who attempted to repeat the experiments of others. We can well remember the obscure accounts which were published, from time to time, in reference to the different processes, as they were given to the world. This, coupled with the various opinions held by discoverers, by no means assisted even the most ardent experimenter, but rather left him in what has expressively been termed "a fog." The mists of uncertainty, however, were gradually dispelled; and at the present time photography stands out as one of the most complete applications, both in rationale and practice, of any which have been made of the various branches of science.

These remarks are here made, because we regard the Calotype as the first elegant and complete branch of photographic manipulation. The discoveries of Daguerre were of great value; but those of Mr. Talbot at least equal them in that respect, and, in practical utility, often exceed them.

We now proceed to detail Mr. Talbot's method of producing his Calotype pictures; and shall introduce the subject in nearly the words used by the inventor whilst describing his earlier processes.

We may, however, impress on our readers the remarks which have been made in reference to the choice of paper. It matters not what process is undertaken in photography—the same chemical laws must be observed, and chemical changes must be looked for or guarded against. In the case of the Calotype, special care is required in this respect to ensure successful results, for the process requires the most delicate manipulation.

The following, therefore, will guide the operator into what we may call the elements of the Calotype process.

A proper paper having been chosen according to the general instructions we have already given, such is to be placed in a solution of nitrate of silver, dissolved in the proportions of—

Nitrate of silver . .	100 grains.
Distilled water . . .	6 ounces.

In the manner described at a previous page (626). The side so placed should be marked by means of a pencil, that it may thereby be easily recognised. The paper is afterwards to be dried in a dark place, and, if not immediately used (which is advisable), it should be kept out of the rays of the sun, or of diffused daylight. As, however, organic matters tend to decompose silver salts, even in the dark, it is better that this paper should only be prepared in such quantities as may be consistent with the immediate requirements of the operator.

The paper is then to be placed, with its silver side downwards, on a solution of iodide of potassium, in the proportion of—

Iodide of potassium . .	100 grains.
Distilled water . .	3 ounces.

By these means the iodide of silver is formed on its surface, which gives the paper a kind of primrose appearance. It is then dried, first being pressed between folds of clean white blotting paper. In this state it is barely sensitive to the action of light; but the process should be conducted by candlelight, or in a dark room. This we may term iodised paper; and, if properly prepared, and all the precautions with respect to cleanliness, etc., having been observed, it may be kept for some time without danger of undergoing any very serious change. However, in our repetition of Mr. Talbot's experiments, we have found that the almost certain presence of organic matter in the size of almost every kind of paper, has a tendency to produce changes which eventually exhibit their effects in

spots, etc., on the surface of the prepared paper, if such be made for any length of time before being used.

The reader will thus observe that the Calotype process depends on a formation of an iodide, in place of the chloride of silver, on the paper surface; and on this depend some of the peculiarities of Mr. Talbot's Calotype process.

Before exposure in the camera, this iodised paper must be rendered more highly sensitive; and this is done by placing the prepared surface on a solution of—

Nitrate of silver	100 grains.
Distilled water	2 ounces
Acetic acid	3 drachms.

To which is to be added an equal quantity of a saturated solution of gallic acid. We may here observe, that gallic acid is but sparingly soluble in water. Mr. Talbot calls the mixture the gallo-nitrate of silver. This solution should, whilst prepared in the proportions we have named, be only made in quantities required for immediate use, because it spoils by keeping.

After the iodised surface has been rendered sensitive by these means, the paper is to be dried; and this process should be conducted shortly before the exposure of the paper in the camera. It may be used with advantage in a slightly damp state, which somewhat facilitates the subsequent process.

The paper may then be used in the camera, in the manner already pointed out for the Daguerreotype process; and the time of exposure will vary according to the sensitiveness of the surface, and the intensity of the light reflected from the object about to be copied. A latent image will thereby be formed; and this is to be rendered visible by placing the paper on, or by pouring over its surface, a solution of the nitrate of silver, acetic, and gallic acids just named. The photograph or Calotype is thereby developed; and this should be done in a gradual manner. Sometimes the development takes place somewhat irregularly, and spots and stains appear. If the exposure has not been sufficiently long in the camera, the picture takes a considerable time before it appears; and, in such cases, the aid of a gentle heat may be called in. The picture may then be fixed by immersing it in a solution of—

Bromide of potassium . .	100 grains.
Distilled water	10 ounces.

After which it is to be abundantly washed with water, and subsequently dried. By these means a negative is produced; and by dipping the prepared paper in a solution of iodide of potassium, a positive may be obtained, provided the gallo-nitrate immersion has been adopted. After exposure in the camera, the gallo-nitrate solution is then used for development in the way already described, and the fixing process immediately follows. This may be done by immersing the picture in a solution of hyposulphite of soda in the manner already described as applicable to Daguerreotype plates at page 639, *ante*. This should be followed by careful soaking in successive quantities of distilled water until all soluble matter is removed. The picture may then be dried and mounted on a piece of cardboard. In washing or soaking great care is required lest the paper become torn and the picture consequently be destroyed, the texture of the paper not generally having much strength.

Such is an outline of the earlier attempts of Mr. Talbot; which, however, have been modified by numerous subsequent experimenters. The same principles generally are involved, and the process is conducted more rapidly, owing to the more sensitive nature of the prepared paper.

The Calotype process, like many others, is not so much in favour as that of the collodion, owing to the numerous details which have to be observed, and the tediousness of its manipulation. The effects, however, are very pleasing; and we may almost call it the most elegant and refined of photographic processes, when it is properly carried out.

The Collodion Process.

This method of taking likenesses, views of landscapes, and in fact of almost all subjects submitted to the photographer, has exceeded all others in its universality of employment. This is not to be wondered at, when we remember that by it we can invariably insure speed, accuracy, and beauty of outline, if ordinary care be observed. There is scarcely a small town in the United Kingdom where a photographer may not be found who will take cheap likenesses by its agency. In fact, the collodion process has often been the refuge of the destitute in search of a means of livelihood, and the annoyance of those who have had recourse to him under such circumstances.

In the hands of a competent operator the process is capable of giving excellent results, and by the aid of science and practice it has been brought almost to perfection. Some of the most interesting objects of nature and art can be copied by it with a minuteness of detail, yet retaining artistic qualities, that leave nothing to be desired. Some splendid specimens may often be seen in the windows of the photographer or scientific instrument maker, such as views of the interiors of cathedrals, halls, mansions, sea and cloud, instantaneous views, etc., etc. But such results are only obtained by those who, possessed of scientific knowledge, are enabled to turn to the best advantage the most perfect kind of apparatus, pure chemicals, and a taste for art. With these preliminary observations, we turn to the practical part of the question, giving first only an account of the ordinary mode of proceeding, and reserving for subsequent pages accounts of the most recent improvements that have been introduced.

Assuming that the student has provided himself with all the apparatus, chemicals, etc., which we have already mentioned, we shall suppose that, under our direction, he is about to take the portrait of a friend, or a *positive* picture of any stationary object. We commence with

positive pictures, because, to the beginner, they afford immediate fruit of his early endeavours.

Positive Pictures. — The process naturally divides itself into the following operations—namely:—

1. Cleaning the glass plate.
2. Coating it with collodion.
3. Rendering it sensitive.
4. Exposing it in the camera.
5. Developing the latent picture
6. Fixing the picture.

The above have been arranged in the order in which they succeed each other; and neglect in carrying out each process individually, will, without the shadow of a doubt, bring inevitable failure as its result; whilst, if conducted in a quiet, persevering, and cleanly manner, success may most justly be expected to reward the operator's attempts. The glass plates are sold, of various sizes, by the instrument-makers; and the material should have a high polish—be perfectly free from specks or blemishes of any kind. For this reason common window-glass is useless; and a kind, manufactured expressly for the purpose, must therefore be purchased.

1. *To Clean the Glass Plate.*—The methods proposed for this purpose are endless in number. We, however, find the following to succeed as well as any we have tried. Place the plate on a soft linen towel, and alternately rub each side till all free dust and dirt are removed. To ascertain this, hold the plate so that the reflected light from the sky or a candle may reach the eye, by which means any defect may be readily detected. Flaws, scratches, etc., in the glass may thus be seen which would otherwise escape notice. Then, by means of a little soft cotton wool, wash the two sides with a mixture of spirits of wine and liquid ammonia, in equal quantities; this will remove all extraneous solid matter, such as grease, etc.; afterwards wash with distilled water. The plate being dried, must then be held by means of a finger and thumb, placed at opposite corners, over a spirit-lamp, until the surface of the glass presents a brilliant polished appearance, and the whole becomes very hot; this removes a film of air which rests on every polished surface. We have never seen this plan recommended by any photographer; but have no doubt that in many cases it will prove a remedy for a common evil—that of the non-adhesion of the collodion film. We were first led to try it from long practice with Grove's voltaic batteries. The platina in such arrangements is always coated with a film of air; and unless this is removed, the nitric acid never comes in contact therewith. Having observed the effect of removing this aeriform coat in increasing the battery power, we tried it on the glass plate for photographic purposes, and have found, with many whom we have induced to try it, great advantage therefrom. After thus heating the plate, place it on its edges, so that it may rest at an angle against any support; and do not attempt to use it till quite cool, but do so immediately after it has regained the temperature of the surrounding atmosphere, because another film of air or moisture, most probably both, will speedily form on its surface.

By such means a glass plate may be thoroughly cleansed from every kind of matter prejudicial to its employment for photographic purposes; presuming, of course, that the chemical nature of the glass is such as to present no other difficulty. We may here mention, that although glass, in a practical point of view, may be considered perfectly insoluble in any agent ordinarily employed to cleanse it—such is not strictly true. We are inclined to believe that solutions of potash, nitric acid, etc., often employed by photographers to cleanse their glass plates, act in an unexpected manner in producing many of the difficulties which frequently present themselves. We are the more inclined to urge this point on our readers, from having found great difficulty in cleansing glass for the purpose of several experiments on polarised light. If the reader will refer to page 180, in the electrical section of this work, on the second column, he will find some remarks we have made in regard to the value of different kinds of glass used for making electrical machines. We have there remarked, that "If the glass cylinder or plate contain much soda as a constituent of the glass, it will always be greasy and never work well; and hence the necessity of choosing the best glass for an electrical machine." For precisely the same reasons care should be taken in regard to the choice of glass for photographic purposes. Even the mere mechanical action used in rubbing a piece of good glass, by means of a towel, silk handkerchief, chamois leather, etc., is quite sufficient to form minute lines, which are worked thus into its surface, and, therefore, render such uneven. Whilst visiting several mills in the north of England and Scotland, we were surprised to find in a large "doubling" establishment—that of Messrs. Coats, of Paisley—that thick glass rods, which have been employed as rollers, over which the cotton thread had to pass whilst being wound on the spindles, were cut through, in some places, to the depth of a quarter of an inch, by the soft cotton filaments. The two following experiments will impress this fact on the minds of our readers; and, at the same time, will show the necessity of great caution in rubbing or cleansing glass surfaces, whether in the form of lenses in the camera, or of plates intended to receive pictures on their surface.

Experiment 1.—Into a perfectly clean test-glass or test-tube, pour a weak solution of carbonate of potass; then add a solution of tartaric acid—both being made by means of distilled water. Immediately after mixing the liquid, rub the sides of the glass, by means of the *smooth* end of a glass stirring-rod. After a short time, minute crystals of bitartrate of potass will be deposited only on those places which have been rubbed with the rod. Now, as we know that crystals always require an angular projection to cause them to be deposited on a surface, we may justly conclude that such has been produced on the inside of the glass, although by means seemingly inadequate to produce the effect, and invisible to the eye.

Experiment 2.—Rub a piece of plate or window-glass repeatedly in the same direction, by means of an apparently soft towel. Allow it to cool from the production of heat which the friction will evolve. If the rubbed surface be then breathed on, a series of minute lines may generally be observed on holding the glass at an angle, and by viewing it by the light reflected from its surface.

We thus observe that the polished surface of any body, no matter how hard it may appear, may be readily affected by others of a much softer nature, by rapid or peculiar mechanical action. As an expansion of the illustrations we have offered, we may state that a piece of soft iron, revolving rapidly, will cut a piece of hard steel as readily as a knife would a loaf of bread. We may, therefore, urge on our readers an excellent old saying of the Greeks—"hasten slowly"—as a motto to be held in mind when they are preparing plates for the camera.

One of the best tests of the perfect cleanliness of a glass plate, is the even condensation of moisture on every part of its surface. This indicates that its external condition is uniform in every place; and such is exactly the condition which an aspirant to success in the art should at all times endeavour to obtain.

After the plate is thus prepared, be careful to touch it in no part, except at those edges which are at the extremes of its diagonals. This rule should be observed carefully throughout all the subsequent processes: the only exception allowable, is that in which the plate must be held in certain positions during the time the collodion is poured on its surface—a process which we have next to describe.

2. *Coating the Plate with Collodion.*—The next step in our process is that of coating the cleaned plate with collodion. But before describing this, we shall give some directions with respect to arranging the camera, and thus of having it ready to receive the sensitive plate. The professional photographer generally has an assistant, who cleans the plate whilst the operator is getting the camera ready for it. As, however, we presume that our readers may work alone, we need scarcely state that the camera should be adjusted before the plate is coated and made sensitive. Any disturbance of the focus can be easily corrected immediately before the sensitive plate is introduced into the camera.

The person whose likeness is to be taken should put himself into a natural position, free from constraint, and in such a posture that all the muscles of the body may be, comparatively speaking, at rest. In our opinion, there is a vast deal more art in *sitting* to have a portrait taken, than in *taking* it. Almost every one experiences a degree of nervousness; and each determines to maintain a strict and grave deportment, which, by its affectation, increases, or, at all events, disposes to beget, nervous irritability. Hence, most persons complain that their "likenesses" are not like them; nor, indeed, can they be, when individuals practically determine, on such occasions, to assume airs and graces which, like ladies' best dresses and drawing-room furniture, are only used on "state occasions." Another point of importance is that the person should be in good health, and free from excitement or fatigue. When writing this article, the author employed a first-rate photographer to take his likeness, for the purpose of testing various collodion mixtures. Out of about twenty taken in one day, not two agreed in the expression of the face, due to our over-exertion, anxiety for success, and, by the way, the intense and fatiguing heat of the weather.

A support of some kind is required to maintain the head in its position; because the muscles of the neck are apt to become fatigued if a long "sitting" be necessary. Contrivances of this kind are of various shapes; two of which are represented in the annexed figure One of these (No. 1), as will be observed, may be attached to the back of a chair; whilst the other, (No. 2) stands on its own pedestal. It will be found, in practice, that the latter is the most convenient, because it is easily adjusted to any position. The rest for the head is the curved portion at the top of each figure; and should be so arranged as to support the head of the sitter just behind each ear; and, of course, out of sight with respect to the camera, or it will be included in the portrait. These supports, however, generally give a rigid and unnatural appearance to the pose of the person. Sometimes men thus taken appear as if they had at the moment been afflicted by a stiff shirt collar pressing the chin, and, therefore, the face, upward.

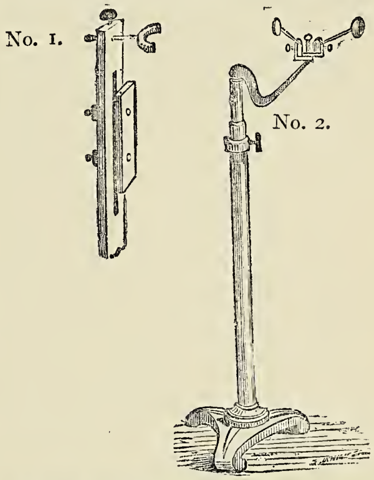


Fig. 337.—Supports for taking Likenesses.

In arranging either of these supports, therefore, they should be employed solely as rests to support the head, and to prevent fatigue; and not as a framework, by which a rigidity of position would be induced, and stiffness of carriage promoted.

Having adjusted the position of the sitter, place the camera in front of him; and after removing the brass cap from the front of the lens, adjust the camera in such a position that

if you are taking the bust only, its image shall occupy the centre of the ground-glass plate. This is of course done by looking at the image on the ground glass; by shifting the camera to and fro; and focussing the lenses until a clear and distinct picture is observed.

In obtaining a good focal view, pay especial attention to the forehead and face, which of course form the essential points of the picture: and, in getting these correctly, the value of your lenses will at once be tested, and your full skill and judgment called into exercise; on which, in fact, success will depend. These points having been attended to, the ground glass is still to be left in the frame, so that the focus may be re-adjusted just previous to introducing the sensitive plate into its place, as already mentioned.

Although a plate coated with collodion only is unacted upon by light, still we shall presume that all the subsequent processes, except that of taking the likeness, are conducted in what is called a dark room. This room, in the language of photography, is considered to be a place into which not a ray of light of any sort, except of a *yellow* colour, is allowed to enter; such ray, as we have already remarked, at page 619, *ante*, having little or no action of a chemical nature on the sensitive plate. The professional or amateur photographer often goes to considerable expense in arranging this "*sanctum sanctorum.*" We have had the good fortune to see a considerable variety, even from a room fitted with every convenience which science and means would permit, to one wherein a crazy four-post bedstead, covered with extremely ancient bed-furniture, did duty in the waggon of a travelling operator. Leaving the choice of position or place to our reader, we may remark, that an abundant supply of soft water running from a tap, a sink to carry away waste water, a large firm table, and complete absence of daylight, are the essentials of such a place. A sitting-room may be used, in which the windows are completely closed from external light by means of thick brown paper pasted over them; and the water-supply may be that of a jug and pails, with such other contrivances, when circumstances render greater conveniences unattainable. Of course the peripatetic photographer must take his dark room with him, and we must leave him to suit all his arrangements according to the circumstances in which he finds himself.

Of course light of some kind must be used to enable the operator to proceed. Some persons employ a tallow candle, others a low gas-flame; but both of these have a prejudicial effect on sensitive plates. In some instances a little daylight is admitted through thick orange-coloured glass. We have always preferred to use a spirit-lamp, charged with spirits of wine, in which *dried* table salt has been dissolved. This affords a flame of a dingy yellow colour, perfectly inactive from the absence of chemical rays—affording both sufficient light to work by, and also a ready and necessary source of heat when the plate has to be dried, etc., after fixing and washing. It is essential that the dark room should be kept scrupulously free from dust and dirt, otherwise it is more than likely that such will settle on the delicate collodion film, and spoil the plate. It is a good plan to wet the floor of the room, especially in summer-time, which will prevent the fine particles of dust rising as the operator moves to and fro.

A clean glass plate being held in the hands, the iodised collodion (see p. 338, *ante*) may be poured on it in the manner represented in the annexed engraving. The plate should be held

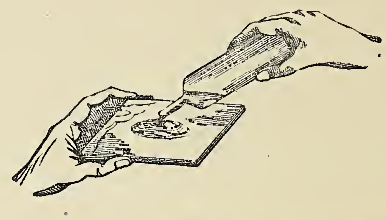


Fig. 338.—Pouring the Collodion on the Glass Plate.

quite horizontally in the left hand; the collodion bottle being placed over the centre, so that the liquid may spread evenly over every part until the edges are reached without its overflowing them. The object is to give a thin and perfectly even film to the entire surface of the glass; and when such is obtained, the superfluous collodion is to be poured off by holding the plate over a wide-mouthed glass bottle, so that its diagonal may rest on the neck (see Fig. 339). The plate is then to be restored to a horizontal position for a few seconds, in order that the regularity of the film may be regained. This operation is one requiring both care and practice; and can only be successfully performed after the operator has had some little experience. It should, however, be done calmly and without haste, to ensure good results; and it is advisable not to proceed further with any plate which does not present an even coating. Such are easily cleaned for another trial, in the manner already described. Great care is to be observed in the mode of removing superfluous collodion after the glass plate has been covered with the liquid.

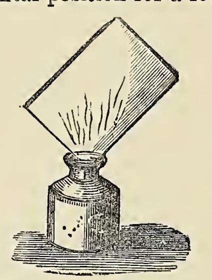


Fig. 339.—Draining the Plate.

Presuming that an even, spotless, and otherwise perfect film of iodised collodion has been obtained, the next step is to render it sensitive.

3. *To render the Coated Plate Sensitive.*—The choice of a "bath," as it is termed, for rendering a coated plate sensitive, has been a subject of great discussion amongst photographers; and almost every authority has propounded views and directions, which, from their diversity, are eminently qualified to perplex a beginner.

Although a middle course is at all times the safest in which to steer, it is most difficult to find that position. Some have recommended a proportion of nitrate of silver in solution as the most sensitising, which is much less than half the quantity that others consider essential to success. It has hence been found necessary to include various recipes in all of the works which have been produced that deal with this subject; and the recommendations, both scientific and empiric, which have thus been published, may safely be called "legion."

We confess to a difficulty in recommending any specific course to our readers; but we shall do well to inquire into those contingencies which may affect the best *formulæ;* and afterwards we shall endeavour to suggest, not *ex cathedrâ*, but in deference to the opinion of every one who may differ from us, as to what is the best course for the student to pursue. Still, we must leave him to gather by experience what books can never teach him.

The object which we have to attain, is that of making the coated plate sensitive to the action of the chemical or actinic rays of light; and this should be so effected as to require the shortest possible exposure in the camera to produce the picture. For this end, a salt of silver must be formed on the surface of the iodised collodion plate, which will meet our demands. The difficulty lies in satisfying all the conditions which are essential to success.

It would appear, at first sight, that the simplest mode of rendering a plate sensitive, would be that of immersing it in a solution of nitrate of silver, of any strength within certain limits; but it is found in practice that the result of developing depends very much on the strength of the silver solution employed. Again, unless the "bath" is prepared by the addition of certain substances, the sensitive character of the film will be impaired, owing to a loss of a portion of its iodine when it comes in contact with the silver solution. Even the constitution (if we may so call it) of the film itself, in a mechanical point of view, may be either modified or injured by neglecting certain precautions. In this case, of course, all subsequent operations would be useless, and the process must be repeated with a fresh plate. Photography allows of no tinkering.

The student must not suppose that we are presenting imaginary difficulties in his way. We are only anxious to anticipate circumstances with which he may have to contend; and thus, by giving him preparatory hints, we hope to enable him to avoid both the Scylla and Charybdis of photographic manipulation.

From our own experiments, we recommend the following silver solution as an average one:—

Nitrate of silver . . .	60 grains.
Distilled water	2 ounces.
Iodide of potassium . . .	1 grain.

Dissolve the nitrate of silver first in an ounce and a-half, by measure, of distilled water; the iodide of potassium may then be dissolved in the remaining half-ounce of water. The two solutions should then be mixed and agitated together in a clean glass-stoppered bottle, and subsequently filtered through clean filtering-paper. This solution we have found to act well with good positive collodion. When, through repeated use, it has become replete with iodide of silver, a further addition of a solution of the nitrate of silver, without the iodide of potassium, should be made; and the whole is then to be filtered. A few grains of kaolin, or pipe-clay, may be added to neutralise an excess of free acid, which will occasionally be present. This excess may be easily tested for by dipping into the solution a piece of blue litmus paper, which may be obtained of all practical chemists and instrument makers in little books. If any free acid be present the paper will turn red. In that case the kaolin should be added in small quantities at a time, until the liquid ceases to show an acid reaction by the litmus paper test.

Many writers have recommended a less proportion of nitrate of silver; others have advised the addition of more iodide of potassium; some recommend the use of a little acetic acid and alcohol to such a solution. We can only state that our own opinion is, that all these additions are, and have been, recommended to meet cases which may, or may not, occur to other experimenters. For instance, the nature of the collodion incessantly varies, by reason of the chemical changes to which it is subject; and with every desire to assist the beginner, we must state that experience, patience, and watchfulness are the sole guides or assistants on which he can at all depend. We shall, however, give a variety of recipes for these and other solutions which have been proposed by various experimenters, in another part of the work, leaving to the student the chance of trying each until an average of success attends his labours.

The solution having been prepared, it should be poured into an upright bath or trough, such as is illustrated in the annexed engraving. These are generally made of gutta-percha; but an upright glass, or porcelain trough, will answer just as well; we prefer the latter for many reasons. The length and breadth, of course, must depend on the size of the glass. If the vessel be upright, and not oblique, it should not be less than half an inch wide. Sufficient silver solution should be employed as will nearly fill the vessel; and, of course, it should be in such a quantity as will cover the whole of the glass when introduced therein. Some operators use flat dishes for this purpose; but they run risks of spoiling the plate, owing to dust, etc., settling on the surface of the solution.

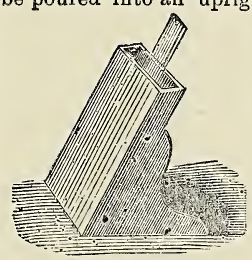


Fig. 340.—The Silver Bath.

When an upright trough is employed, the plate should be placed in a frame, for the purpose of supporting it whilst remaining in the solution. This arrangement prevents the necessity of touching the plate, or of wetting the

finger; and, as such, is conducive to cleanliness and convenience. One of these frames is represented in Fig. 340.

The plate, having been coated with collodion, should, whilst still wet, be placed in the frame, and must then be *steadily* and *continuously* introduced into the silver bath. This should not be hastily done, less the collodion film may be removed or injured; and no stoppage should be allowed, because that would produce a distinct and damaging mark on the surface. Of course this must be done in the dark room. After leaving the plate in the bath for about a minute, it should be gradually withdrawn; and after remaining a few seconds in the air, is again to be introduced, and may be left there for about two minutes longer. On removal, it should present an even opal appearance, and be perfectly free from spots, lines, etc., or otherwise it will be quite useless. The length of time during which the plate should be in the bath, depends on a variety of circumstances; and hence we have only mentioned an average, leaving to the experience of the operator to decide in special instances. It should then be placed in the dark frame, the lid of which should be carefully closed; and no time must be lost in transferring it to the camera, lest its sensitiveness may become lessened.

4. *Exposing the Plate in the Camera.*—The plate having been made sensitive, and placed in the dark frame, is now ready to be transferred to the camera; and in removing it, a cover of black cloth or velvet should be thrown over the whole before it is taken from the dark room. This precaution prevents any chance of a ray of light entering through any imperfection in the construction of the frame itself. The operator should again examine the image formed in the camera; for although only two or three minutes may have elapsed since he focussed his lenses, still persons are very apt to shift from their position; and therefore, of course, by so doing they will lessen the sharp appearance of their image on the ground glass. The sitter must be requested to remain perfectly still; and having arranged him in the most advantageous position, and re-focussed the lenses, the brass cap in front of these should be put on to the tube, so as to prevent the ingress of any light into the body of the camera. The ground-glass frame is now to be removed, and the prepared plate must take its place. It is best put into position by lifting it up with the black cloth, which should be dextrously covered over the top of the camera, whilst the frame containing the plate is inserted in the slide. The lid or flap in front of the plate is now to be removed; and after again enjoining complete stillness on all present, gradually remove the brass cap in front of the lenses. The rays of light will now fall on the sensitive plate, and produce their chemical effect.

The student will expect that we should here give him minute directions as to the length of time during which he must expose the plate; but this it is impossible for us to do. The weather, both with respect to the amount and colour of daylight, has a great effect; then, again, the nature of the collodion employed, the colour of the face and dress of the sitter, and various other contingencies, render the question of great uncertainty. The same collodion used on two different days, or at different periods in the same day, may produce different results. As a general rule for the beginner, an exposure of from fifteen to thirty seconds may be adopted; and as he gains experience, he will soon be enabled to estimate the value of the different causes which tend to render a picture more or less perfect. We shall have to speak more fully of this presently, when we refer to the developing process. Presuming that the plate has been sufficiently exposed, the brass cap should now be replaced in front of the lenses; the flap is to be shut down in front of the plate; and the frame should be removed from the camera, so that the black cloth shall completely cover it. The frame, etc., are now to be removed into the dark room, for the purpose of development.

5. *Developing the Picture.*—The tyro will very likely imagine that on removing the plate from the frame, he will observe the picture at once on the prepared surface. Such, however, never occurs: the plate presents, as near as possible, the same appearance after, as before, its exposure to light; and the latent picture must, therefore, be developed—that is, brought out into a sensible form by means of further chemical action. The philosophy of this process is easy of explanation: the iodide of silver, formed on the surface of the collodion when it was immersed in the silver bath, has now become changed. That portion which has received the rays of light will be differently acted on, by the addition of certain agents, to that on which no change has taken place by luminous rays. On pouring the developing solution on to the surface, this difference gradually becomes apparent as the picture unfolds itself on the glass surface. But we now proceed to the practical part of the operation.

The door of the dark room being closed, and only a faint yellow light employed, the lid of the frame should be removed, and the glass plate is to be carefully taken out, and placed, with the uncoated surface downwards, on a level stand, resting in a large porcelain or glass dish. Such an arrangement as this is represented in the above engraving.

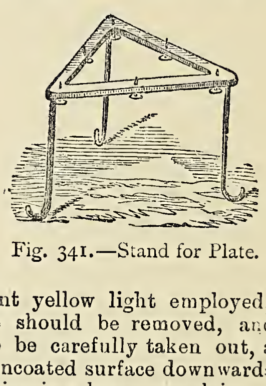


Fig. 341.—Stand for Plate.

In the absence of a stand of this sort, two glass rods may be placed across the edges of the dish; and on these the plate may rest; or even

an inverted tumbler or wine-glass may be employed. The object is to keep the plate quite horizontal during the development, and to receive, in the dish beneath it, the superfluous developing fluid which will run from the plate.

We would here urge on the operator to employ each vessel in his photographic practice for its special use only. By so doing, he will avoid any risk of mixing solutions, and of thus rendering them useless. Every chemical agent employed throughout the processes we have already mentioned, and are yet to describe, must only be brought together when wanted. If mixed carelessly, each solution, if present in only minute proportions, will certainly impair, if not destroy, the utility of any other. A place (or vessel) for everything, and everything in its place, should be a golden rule in photography.

The plate being thus arranged, the developing solution should now be poured on to it from a glass measure, similar to that represented in the annexed figure; and this should be done in a careful manner, so that the whole of the plate surface may be covered evenly with the liquid. The latent image will now gradually appear; and much care is required that the process is not carried too far, for fear of spoiling the picture. We must, of course, therefore leave the study of its indications to the judgment of the operator, who, although perhaps failing at first to arrive at the *exact* point at which development should stop, will eventually, after a few trials and failures, acquire the necessary experience. As soon as the picture is sufficiently brought out, all further action should be stopped by washing the plate well with cold water. This may be done by holding it cornerwise under a gentle stream of water running from a tap, or by pouring water in abundance from a jug with a narrow lip. It is extremely essential that this washing should be as complete as possible, so that every trace of soluble matter may be removed. This being effected, the next step will be that of "fixing" the picture. But before we proceed to that, we must give our readers recipes for making the developing solutions to which we have been referring.

Fig. 342.

It will at once be perceived, by looking over the annexed list of solutions, that considerable latitude is assumed by various photographers. This is partly owing to the varying nature of the collodion employed; to the manipulation of the operator; and, in many instances, to the peculiar views of those who follow the art. We have, however, deemed it desirable, for the purpose of making our subject as complete as possible, to lay before the student ample opportunities for the exercise of his skill, judgment, and choice, with respect to solutions.

Developing Solutions for Positive Pictures.

Protosulphate of iron . .	40 grains.
Nitric acid	3 drops.
Acetic acid	30 ,,
Alcohol	20 drops.
Distilled water	1 ounce.

Or—

Protosulphate of iron . .	8 grains.
Acetic acid	1 drachm.
Nitric acid	2 drops.
Water	2 ounces.

6. *Fixing the Picture.*—The last-described process having fully developed the latent picture, it only remains to secure this from further change by the action of light. The result produced is simply that of removing every trace of those salts of silver which would become changed if white light were allowed to impinge on their surface.

There are two fixing agents which are chiefly employed by photographers, each of which has the power of removing the sensitive silver salts: these are the hyposulphite of sodium, and the cyanide of potassium. The first-named of these salts was largely used in the early stages of photographic practice; but at the present time, the cyanide of potassium is mostly employed as a fixing agent; and as such we have, from our own experiments, to add our testimony to its value.

The process of fixing is extremely simple. Either of the following solutions being employed—they are to be poured over the developed picture, and a portion is to be retained on its surface; or the plate may be dipped into a dish containing the solution, and be gently moved about in it. The soluble and changeable salts of silver are thus removed, and any risk of injury is entirely prevented when the picture is subsequently exposed to daylight. After remaining in the fixing solution for about two minutes, the plate should be abundantly washed by means of soft water. We always employ distilled water in the last washing; because river and spring water contain salts, which are left, to a minute extent, on the surface of the plate, and so dim its lustre, and, consequently, lessen the brilliancy and purity of the picture.

After the picture is thus thoroughly cleansed from every impurity, it may be left to drain, and to dry gradually. The usual method, however, is to hold it for a short time over a spirit-lamp or gas-flame; which, of course, speedily causes the evaporation of all moisture from its surface.

For all ordinary purposes the picture may now be considered finished, with the exception that it requires coating with a black varnish; which has the twofold effect of preserving the collodion film from injury, and of also increasing the effect of light and shadow. This varnish is sold by all photographic chemists; or it may be made by dissolving a little black asphalte in mineral naphtha. This should be poured on to the collodion surface, and left to dry. Some persons varnish the collodion surface with the best white mastic varnish, before applying the black coating.

Either of the following solutions may be employed to fix the picture. In that of the cyanide solution we have given considerable latitude; but it is advisable that the student

should commence with a weak solution, and continue its use until his experience is sufficient to guide him safely in the employment of stronger kinds.

Fixing Solutions.

Hyposulphite of sodium .	4 ounces.
Water	6 ,,
Or—	
Cyanide of potassium .	6 to 12 grains.
Water	1 ounce.

It will be unnecessary for us to enter, at present, into a description of the modes of colouring positive collodion pictures, because we shall refer to this in a separate article. We may, however, mention a few causes which lead to failure in the early attempts of those unacquainted with the delicacy of photographic practice; and we shall discuss these in detail.

First, we may refer to the cleaning of the glass plate. This, we already have stated, is a matter of the highest importance, and sometimes one of some difficulty, because of the nature of the glass itself. The electrician, as already stated, is well aware that no two glass plates, in the plate machine, will give off an equal amount of electricity when similarly employed, although they may be of exactly the same size. This is chiefly owing to the chemical constitution of the glass. Now, similarly in photography, the quality of the glass, to some extent, influences the photographic result; and such being the case, the operator cannot be too cautious in the purchase and choice of the plates he employs. We have already drawn special attention to this at a previous page. In cleaning the plates, every precaution should be taken to prevent the presence of grease, grit, or dirt of any kind; and the least touch of the finger on any part of the cleansed surface will most certainly produce an ugly spot at that place. Cloths, etc., used from time to time, gradually acquire grease and animal matter from the hands of the experimenter, and so communicate objectionable matter to the plate. Hence, an abundant supply of clean cloths is essential to success in the earlier steps of taking collodion pictures. Worn-out Indian silk pockethandkerchiefs are very useful.

The collodion itself varies, according to the source whence it is obtained. Each maker considers his to be the best; but we advise the student, after making repeated trials, to keep to that which he finds to suit his purpose, and not to heed the various recommendations of his friends, or others, unless they are backed by decided proofs of superiority. Generally speaking, each maker maintains the regularity of the article he sells: and when once the student has so far succeeded in adapting his bath and developing solutions to one kind of collodion, he will only have the trouble of going over the old ground again, in attempting to suit his practice to the production of a new maker. Much, therefore, depends on making a first and proper choice of the collodion. The makers, we may here state, are always glad to receive suggestions for the improvement of their apparatus, chemicals, etc.

For the silver bath, a thousand-and-one advices and recipes have been given: indeed, their name is legion. The object of course is, that when the collodionised plate is immersed in the bath, its surface shall be made as highly sensitive as possible, and that each part should be equally so when compared with another. Sometimes the bath is too acid, and at others too alkaline. The former evil is remedied by the addition of a small piece of kaolin; and the latter by the addition of a drop or two of nitric or acetic acid. Now, without going far into practical chemistry, we may state that a piece of litmus paper will turn red in an acid; and a piece of turmeric paper turns to a deep brown in an alkaline solution. These may easily be obtained; and by them the bath may at once be tested. The strength of the bath is subject to continual variations; because, every time a collodionised plate is introduced, a portion of silver is withdrawn, and a small portion of iodine is left behind. Now these facts must be borne in mind, because they necessarily influence the process to a great extent. Fogging is the result of an improper state of the bath; and from whatever cause such may arise, it is of importance that the remedy should be instantly applied. This tendency is generally removed by the addition of a small portion of nitric acid, so that the super-alkalinity of the bath may be destroyed, and a very slight acidity be produced. This is a point which, having named, we must leave to the judgment and skill of the operator.

Besides the alterations of the bath, produced by the causes to which we have referred, the student must bear in mind that each time a plate is introduced, a small quantity of ether and alcohol is left behind. This produces a decided harmful effect in the end; and the only plan is to renew the bath entirely.

We may here state that the silver can easily be recovered, in the form of chloride, from used-up baths, by precipitating with a solution of common salt. It may be reduced by means of heat, in a crucible, to the metallic state, if mixed with cyanide of potassium; which, however, is perhaps too troublesome a process to most of our readers. Photographic chemists and metallurgists, however, will purchase it at its commercial value; and this hint may therefore be of use to those whose means do not permit of extravagance in their photographic pursuits.

The developing solutions, like the sensitising bath, have been the subject of enormous variation in the proportion of their ingredients. We shall not enlarge thereon, because we shall only fall into the error of those who have preceded us, by giving advice for circumstances over which we can have no control, not being present to observe them. The student should watch the effect of the different strengths of the solutions he employs, and he will thus gain more knowledge by a few trials, than he could do by perusing any number of works on the subject.

Abundance of washing removes almost every chance of subsequent change in a positive pic-

ture. We strongly advise that the last washings should always be performed by means of *distilled* water.

In choosing the transparent varnish for the collodion surface, care should be taken that it is such as not to crack when dry. The same may be said of the black varnish used for backing-up the picture. Each of these can, generally speaking, be depended on when purchased of the photographic chemists, as they specially prepare these varnishes for the use of photographers.

Having thus detailed the processes and the difficulties, so far as obtaining positive collodion pictures is concerned, we pass on to give directions for obtaining negatives; and shall then describe the best modes of printing paper positives from them.

Negative Pictures.—Hitherto our attention has been confined to those pictures that are taken solely as produced on the silver plate of the Daguerreotype, or on the glass plate coated with collodion, both as single and positive pictures. As the popularity of photography extended, a new want developed itself; it was that of multiplying the number of pictures obtained by the collodion and analogous processes. Of course the Daguerreotype plates were incapable of such multiplication, as each must be taken separately. But, by obtaining negative pictures on glass, we are enabled to multiply positive pictures obtained from them to any extent that may be required. It will be unnecessary here to enter into any description of the characteristics of negative and positive pictures. This has already been done at page 627, *ante,* and illustrated by Fig. 322, the negative, and Fig. 323, the positive picture, where, also, an elementary description of "printing" from a negative picture has been given to produce a positive.

The remarks, advice, and precaution which we have already given, are equally applicable in reference to this part of our subject. We, however, shall find that in some respects the materials employed, and the manipulative processes, vary from those which are followed in producing positive pictures; and it will now be our duty to point such out to our readers.

The plates are to be prepared with scrupulous care after the manner we have already stated, and are then to be coated with collodion prepared expressly for the purpose. This is generally sold under the name of "negative collodion," and contains more pure collodion, in each ounce of the liquid, than that employed for positive pictures. The following recipe for negative collodion is recommended by Mr. Hardwich:—

Purified ether, sp. gr. ·720	5 drachms.
,, alcohol, sp. gr. ·825	3 ,,
Soluble pyroxyline (gun-cotton)	3 to 6 grains.
Soluble iodide of ammonium	3 to 4 ,,

Although we have introduced the above recipe, we still advise the purchase of the collodion by the student, as being the best course he can pursue. In doing this, however, he must particularly ask for collodion fit for producing negatives.

After having obtained a good coating on the surface of the glass plate, it must be made sensitive by means of the silver bath; and in this, considerable variety of constitution has been recommended. The student must bear in mind that a positive picture is required to give a distinct appearance of surface by light *reflected* to the eye; and this requires but a moderately thin coating of collodion. Now a negative picture must have depth and body, because its value and effects depend, in use, on the differences of tone produced by the light *transmitted* through it when paper copies are taken from it. Hence the various modifications required to produce these results in negative pictures during the preparation of the plates.

This is a question of great importance. Generally speaking, it is not important that a negative picture (except in the case of likenesses) should be taken rapidly. Admiring, some time ago, a photograph of an interior of one of our abbeys, which was done in excellent style, we were informed that the operator would prepare what we may call a "slow" negative, and after arranging the plate properly in the camera he would leave it thus for two or three hours, a course which in this special case led to great success in producing a negative for printing the positives.

We annex some recipes for making the silver solution, or bath, which we have gathered from various sources; and the student will do well first to try them in the proportions named, which, however, he can modify as his experience permits, and circumstances require. We need scarcely repeat, that the ever-varying qualities of the collodion he may employ will frequently require such modifications in practice. A knowledge of this can only be gained by experiment under special circumstances; hence our duty cannot go further than to indicate, as complete direction to ensure constant success is entirely impossible.

Silver Bath for Negative Pictures.

Nitrate of Silver	30 grains.
Iodide of potassium	$\frac{1}{4}$ grain.
Distilled water	1 ounce.

This solution may be made by first dissolving the nitrate in a portion of the distilled water, and the iodide in the remainder. The two solutions may then be mixed together for use, and be filtered if necessary; or, the bath may be made by dissolving 200 grains of nitrate of silver in six ounces of distilled water. Into this place a collodionised sensitive plate, and leave it in the bath for twelve hours. Sufficient iodide will be removed from its surface to iodise the bath.

The plate being made sensitive, is then to be exposed in the camera, as when positives are being produced; but, as a general rule, the exposure should be of longer duration. Here, again, definite directions are impossible, because of the great variety of contingencies, such as weather, amount of light, temperature, etc., which have to be taken into account.

After due exposure, the plate is taken into

the dark room to be developed. A different kind of solution is employed for this purpose, to that used in developing positives, although the process, so far as manipulation is concerned, is similar. Much care, however, must be taken to produce the best result. The process should be conducted slowly, and the effect of the developing solution must be constantly watched. When the operator conceives that a good depth of tone, and decision of light and shade is obtained, the process must be immediately stopped, and the plate should then be abundantly washed with cold water, preparatory to fixing. We annex recipes for various developing solutions, as follows :—

Developing Solutions for Negative Pictures.

Protosulphate of iron	1 ounce.
Acetic acid	12 drops.
Distilled water	1 pint.

Or—

Pyrogallic acid	5 grains.
Glacial acetic acid	40 drops.
Distilled water	10 ounces.

This solution requires filtration before use.

Another solution, as follows, may be used :—

Protosulphate of iron	6 grains.
Glacial acetic acid	5 drops.
Distilled water	1 ounce.

Or—

Pyrogallic acid	4 grains.
Glacial acetic acid	60 drops.
Distilled water	4 ounces.

Our readers will here perceive the extraordinary latitude which is given in the choice of developing solutions. We must, however, repeat, that whilst we have employed each of the preceding, and scores of others, we do not venture to say which is the best, because the circumstances under which they are employed vary so much.

Presuming that the operator has succeeded in properly developing the picture, the next process, after careful washing, is that of fixing it. This is done by immersing it in a bath, or pouring over it a solution of hyposulphite of soda, which may be of the strength of—

Hyposulphite	3 ounces.
Distilled water	16 ,,

The picture must then be well washed in cold water, as already recommended, for positives, and so all traces of soluble matter must be removed.

As a negative plate has to undergo what we call comparatively rough usage, its collodion side must be protected in some way to prevent its destruction. This is done by coating it with a thin layer of varnish. The plate must first be gently heated, and the varnish is then to be poured on so as to cover the coated side on every part, most evenly. After the whole surface is covered with the liquid, the superfluous quantity should be drained off, by inclining one end of the plate until it is pretty well cleaned, in a similar manner to that described and illustrated at page 644, where instructions were given in reference to making a collodion plate sensitive. The plate is then restored to its horizontal position, and left to dry, being carefully covered over to prevent dust or dirt falling on its surface.

The following varnishes have been recommended for this purpose, as suitable on account of their transparency and other qualities ; but the operator can purchase those of a proper kind of the photographic chemists. The object to be kept in view is, to have a varnish which shall be transparent, and not liable to crack when it becomes dry.

Negative Varnishes.

Mastic varnish, diluted till of a thin creamy consistency.

Schnee's varnish, which consists of white lac dissolved in spirits of wine.

Copal varnish, of the consistency of thin syrup.

It sometimes happens that the depth of shade, in some negatives, does not sufficiently contrast with the lighter portions of the picture : the result is, that a good print can scarcely be obtained from such. To deepen those tones, we have tried baths or solutions of the bichloride of mercury, sulphate of iron, gallo-sulphate of iron, iodide of potassium, etc., of various strengths. A well-known photographer recommends the following solution, which can be applied after the picture has been fixed, and of course before varnishing, namely—

Iodine	1 grain.
Iodide of potassium	1 ,,
Water	1 ounce.

The picture is to be covered with this solution, and to be left for five minutes: the process may be conducted in daylight. A fresh development in the dark is then required, by means of the following solution :—

Pyrogallic acid	2 grains.
Glacial acetic acid	15 ,,
Distilled water	1 ounce.

This is to be poured over the plate a few times. To this solution may then be added a few drops of a twenty-grain solution, to the ounce of water, of nitrate of silver. This new solution is then to be poured over the plate. The iodine and pyrogallic solutions may be alternately used, until sufficient intensity has been obtained. The picture is then to be well washed, and afterwards varnished. The inventor of the plan states that, as an intensifying process, it is to be preferred to that of the bichloride of mercury ; and our own experiments confirm that view. The student will arrive at some successful results by taking the observations we have made, rather as a guide to his own experiments, than as final dicta. In hurried and unregistered trials with various solutions, we have occasionally hit upon successful results. We, however, do not recommend such a course to our younger readers ; because, although permissible in those having experience, it engenders a careless habit in the beginner, which, of all things, is most to be avoided in scientific pursuits.

We have thus given, so far as we can judge, the most definite directions for obtaining good negatives. Our next course will be to show how such may produce positives by means of prepared paper of various kinds.

Printing on Paper from Negatives.—We have already described, at all events for our present purpose, sufficient of photographic processes, so far as the production of positive and negative pictures are concerned. There are numerous other processes that we shall have subsequently to deal with that involve much more delicate methods than those that have been mentioned. But the mechanical details of nearly all involve the same principles, and in most cases similar practice. It is on the refinement of detail, and consequently on perfection of result, that most of the recent improved processes depend.

As already mentioned, the object of a negative picture of any kind, is that of enabling us to multiply from it any number of copies, a number that, with proper precautions in taking the negative, may be almost considered indefinite. In fact, relying upon this, many photographers keep the negatives of their clients in stock, so that at any time they may supply them more positive copies. This adds greatly to the pecuniary value of photography. Publishers of illustrated works similarly employ electrotyping. Instead of using the original woodcut as produced by the artist, electrotype copies in copper are taken and employed in the printing press. All the folio plates, and many other illustrations, in the present work, have been thus produced; in no instance indeed has the original woodcut been used. The reason of this is evident when it is stated that the woodcut would speedily be worn out, and sometimes irreparably damaged in the printing-press, whereas by the electrotype process, any number of copies equal to it in every respect may be produced at a comparatively trifling cost.

The printing of pictures from a negative plate is effected by means of sensitive paper, which the solid parts of the negative protect from the action of the chemical rays of light, whilst the lighter portions permit that influence to have its full effect. The transparent parts of the negative allow the free transmission of light, and thus we obtain a picture on paper presenting, so far as light and shade are concerned, an exact copy of the original.

We regret to say that all attempts to copy the natural colours of objects have hitherto failed. It has often been announced that such has been accomplished; but hitherto no success has actually been attained, although some approximation has been realised. A positive copy, although precisely the reverse of a negative original, yet has all its blemishes and excellences: hence it follows, that unless a good negative is employed, a good positive can never be printed from it. This fact the tyro in photography will do well to bear in mind, as it will induce care and caution in his attempts to produce the negative in the first instance. In our succeeding remarks we refer to taking copies of negatives produced by methods described in the last section: reserving special details of other processes until we describe the latter.

In our earlier pages (see p. 626, *ante*) we gave some elementary experiments, illustrating the process of paper-printing. They were, however, necessarily of rather a crude character, because they were only intended as an introduction to photographic practice. We must now enter more fully into the minutiæ of the process, and so assist the operator in overcoming many difficulties which arise in its pursuit. We shall, therefore, examine each point in detail, so that the successive steps may be fully understood by all our readers. For this purpose, it will be proper that we should divide the process into separate heads; and in its pursuit, we must remind our readers of the necessity of care and complete cleanliness, as of the utmost importance. The following are the different points to which we shall separately call the attention of the experimenter:—

1. The choice of paper.
2. Its preparation.
3. The copying process.
4. The fixing.
5. The toning.

1. *The Choice of the Paper.*—Perhaps this is the most difficult, because it is the most uncertain, part of the whole affair. However much care may be exercised in the selection, still some hidden defect may be expected to appear in some specimens when they are submitted to the photographic process. At the present time, however, there are some paper manufacturers who produce an article intended solely for photographic use; and this, to a considerable extent, modifies the difficulties with which the photographer will have to contend. This is sold under different names, according to that of its maker. There is, however, a general title of French and English prepared paper. Either may be obtained, ready salted and albumenised, of the photographic chemist; and we shall, therefore, dismiss them without further remark, and devote some space for the benefit of those who may be unable easily to procure them. We may observe that the two kinds of paper most esteemed by photographers, are the *Saxe* paper and the *papier Rive*, but there are a great many other varieties.

In the manufacture of all sorts of writing-paper, numerous impurities, in a photographic point of view, are always present. The water employed in washing the rags, in reducing them to pulp, and in subsequent processes, contains common salt, sulphates, etc.; and in two cases within our knowledge, an appreciable amount of lead, or its sulphide, has been detected, owing to the impregnation of the water by that metal as it flows past the mines. Oxide of iron is almost invariably present, and no doubt exercises a decided effect on the results obtained on paper. Minute specks of iron and brass, or copper, sometimes occur that have been abraded from the machinery during the process of making the paper. We do not wish to multiply the difficulties which present themselves to the tyro; on the contrary, we prefer that he should know the chances of failure which may continually present

themselves; and, by being forewarned, he may, by patience and care, be equally forearmed.

During the manufacture of paper, a portion of size or starch, and occasionally both, are introduced, for the purpose of giving a smoothness and evenness of surface to the texture, and to prevent the absorption of the ink during writing. Blotting-paper is, in fact, only paper without size. Our readers will be prepared to find that such matters have a decided effect on the nitrate of silver, which is the salt usually employed to sensitise the paper. A drop of the solution of that salt speedily produces a black spot on the hands, owing to the increased or peculiar action which occurs from the presence of animal matter. Generally speaking, animal or vegetable matter is always present in some form during photographic processes; but when so in circumstances beyond our control, it is often a source of great inconvenience.

With respect to ordinary sizing, there is no remedy, for blotting, filtering, or bibulous paper are all objectionable; and the patent paper parchment, which is prepared from these by means of sulphuric acid, is, from other causes, as unfit for photographic purposes.

We have found that the best paper of an ordinary kind, and which is generally to be procured in most places, is common drawing-paper; that is, such as is used for lead-pencil drawing. All cream and blue-laid papers are utterly useless. The plain Bath or satin post may be employed: subject, however, to the difficulties and objections to which we have already alluded. The points requiring attention are—that the surface should be even; not too highly glazed; free from spots; and the paper itself as chemically pure as possible. These results can only be practically arrived at by repeated and careful trials. But the use of all such papers is not desirable, and should not be had recourse to except in what should be the extraordinary case of the photographer having none of the proper kind in hand.

Albumenised paper is generally employed by photographers, because the addition of the animal matter has a very good effect on the appearance of the positive, both during the process and after its completion. The mode of applying this, together with the salting process, we shall presently explain. We may state that as a rule the paper had better be purchased from the photographic chemist when required only in small quantities. Gelatine, starch, etc., have also been used for the same purpose; but they are not so convenient in manipulation, or generally so successful in the result, as the white of an egg, which is nearly pure albumen.

Before proceeding to describe the preparation of the paper, we may state that there are a variety of causes which, independent of the manufacturing faults, produce inconvenience to the experimenter.

In cutting, sorting, and packing writing-paper, etc., it necessarily passes literally through many hands; and each time it is fingered, it acquires, in some part, a portion of grease and common salt. Despite, therefore, of all possible care in selecting a good paper, these accidental circumstances tend to spoil it in some parts. Hence, we often find unaccountable spots, and what are called "stars" on the surface; these being generally brought to light during the fixing process. For these we can offer no remedy; only let the operator be careful that he does not increase their number by his own carelessness.

2. *The Preparation of the Paper.*—If our readers can supply themselves with any of the different sorts of paper, ready salted and albumenised, the remarks we are about to make will be superfluous. But we should not be carrying out the general plan of our work, did we not prevent, as far as possible, the chance of our readers being left to their own resources, without any aid which we can afford them. We shall, therefore, give plain directions for the salting and albumenising process, and then deal with the modes adopted for making the paper so prepared sensitive to the action of light. The latter process is, of course, as equally necessary in its application to paper which may be purchased readily prepared, as for that which may be salted, etc., by the student at home.

The albumenisation and salting of the paper may be thus effected. Break a sufficient number of fresh eggs as to produce two fluid ounces of the white, which must be poured into a clean vessel as it passes out from the shell. Care should be taken not to mix any of the yolk with it. To the clear albumen so obtained, add an equal quantity of distilled water, in which has been dissolved eighty grains of chloride of ammonium (sal-ammoniac). This salt is to be preferred to any other for many reasons, and its action is generally to be depended on. Shake up the albumen and the water together, and when well mixed, pour them into a tall glass jar or bottle, and leave the mixture at rest for several hours. The clear liquid may then be poured into a plate or other flat receptacle, and after adding to it ten drops of liquid ammonia, it is ready for use. Then turn up one corner of a sheet of paper, so as to serve as a kind of handle, and placing the part next to the corner first on the surface of the liquid, gradually draw the whole of the paper so that each portion shall be equally moistened. If this be properly managed there will be no air-bubbles left on the paper surface. It may be left on the liquid for a few minutes, and is then to be hung up to dry slowly in a moderately warm place. The object to be attained is that of an even coat of the albumen, so that when the paper is dry, each portion shall present a regular and even appearance. A good deal must be left to the tact of the operator: if, however, our instructions are carefully followed, there need be no risk of failure. Any quantity may be so prepared; and if it is properly dried, and kept in a dry place, it will remain without change for any length of time. We need scarcely say that it is not liable to alter by the action of light.

The sensitising process, or that by means of which the salted paper is rendered fit for the action of light, should be performed shortly before the paper is required for use, because animal matters, as we have already remarked,

have a spontaneous action on salts of silver. The solution may be as follows, viz.—

Nitrate of silver . . 80 to 100 grains.
Distilled water . . 1 fluid ounce.

This is to be poured into a clean glass or porcelain vessel; and a piece of the paper, prepared as we have described, is to be placed on its surface in the same manner as that recommended for its albumenisation, care being taken that no air-bubbles are left on the surface, and that no part be touched by the finger, except the turned-up corner. The paper may be left in the solution for a few minutes, and is then to be dried in a dark place, because, owing to the formation of the chloride of silver on the surface, it has become sensitive to light. Of course, this part of the process should, for such reasons, be entirely carried on by candlelight.

The strength of the silver solution gradually diminishes as each sheet is taken from it, and therefore an occasional addition of some more nitrate of silver, or of a strong solution of that salt, will be required. When the solution becomes of a brown tint, its colour may be restored by adding to it a small portion of pipe-clay. This is to be shaken up with the liquid, which can afterwards be filtered through some blotting-paper, if requisite. The use of this clay or kaolin in the silver bath has been already mentioned at page 648, *ante*.

3. *The Copying Process.*—To effect this successfully, a copying frame should be employed. It consists of an outer frame, which holds a sheet of the best plate-glass, free from specks, air-bubbles, and, indeed, every other imperfection, which, if present, would be sure to appear on the positive picture, and spoil it. The glass, of course, must be also scrupulously clean. The negative is placed under the glass with the collodion side next to the paper. The prepared paper is placed with its albumenised side next to the negative; and to keep the two in close contact, a back fits into the frame, and is secured by means of two cross pieces therein. Folds of blotting-paper, or soft cloth, may be placed between the paper and back of the frame, so as to press the paper firmly against the negative plate. This is of great consequence, because any crease in the paper would at once spoil the print, and produce general indistinctness of outline. The back of the frame is made to open and shut; so that whilst one part still firmly presses on the plate and paper, another part may be raised, and the progress of the printing examined.

We can give no definite directions as to the length of time required for exposure. We have already often remarked on this point. To illustrate this, we may instance the numerous experiments which we have made solely for the purpose of testing the question. In the morning of a summer day, in clear sunshine, the printing process has been effected in a few minutes; whilst after four o'clock it has required an exposure of from half to three-quarters of an hour to produce the same effect. Occasionally we have noticed an almost entire suspension of actinic effect; but, a few moments afterwards, whilst the sun has been obscured by a thin cloud, the printing seemed to have gone on with increased vigour.

In the hope of giving something like an idea on this point, we have had collodion positives on glass taken during every quarter of an hour, from ten in the forenoon, with little intermission, till six in the evening, in the early part of June, choosing alternately a clear sunshine and dark cloudy weather; and despite all attempts at uniformity in every circumstance, so far as manipulation and chemicals were concerned, our results entirely baffled any hope of affording constant rules. We purposely engaged the services of an expert operator. The best kind of camera, lenses, etc., were employed, together with chemicals prepared with great care, and the experiments were carried on far beyond the range of dust, smoke, etc., in the atmosphere.

Generally speaking, it is better that the positive should be over, rather than under-printed, because, when placed in the fixing solution, it undergoes considerable modification, and every part becomes of a lighter tint. Of course, much depends on the depth of shade, etc., in the negative, other circumstances being equal. We must therefore leave this point to the care and judgment of the reader, who will, by practice, arrive at something like certainty of result, and which experience alone can give.

During the printing process, the paper may be examined in the way we have mentioned, or a piece of the same paper as that in the frame may be exposed under an equally thick piece of plate-glass, and the process of colouring be watched; unless so placed it will deceive the operator, because the glass of the frame exercises a retarding effect on the progress of the chemical changes.

A usual form of copying frame is illustrated in the following engraving: *a* is the outside frame; *b* is the back of the frame; *c c* two bars, which fit into the sides of the frame, and so press the paper and negative together; *d* is a hinge, by means of which either end of the back may be opened, so as to allow of the positive being examined during the progress of printing.

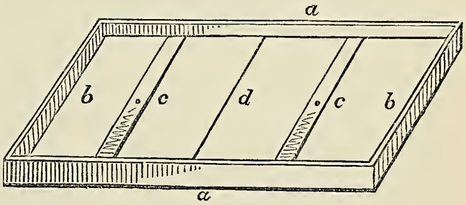


Fig. 343.—Photographic Copying Frame.

4. *The Fixing Process.*—Presuming that the positive has been properly printed, the next step is to prevent further action of light thereon, and so to render the picture permanent. This is effected by immersing it in a bath of hyposulphite of soda, which dissolves away all the unchanged chloride of silver. The proportions of the solution are as follow :—

Hyposulphite of soda . . .	1 ounce.
Distilled water	4 ounces.

On removing the print from the copying frame, it should be abundantly washed with cold water, which removes all substances soluble in that liquid. A solution of half an ounce of common salt, and a small quantity of bicarbonate of soda, is then made in a pint of water, into which the print is to be dipped, to free it from all traces of nitrate of silver and nitric acid. It should then be again washed in abundance of water, to free it from the soluble salts it may contain. The next step is to immerse it, face downwards, in the hyposulphite bath, in which it may remain for a quarter of an hour. It, however, should be continually examined, because the fixing solution has a tendency to destroy the distinctness of outline and gradation of shadow which give the beauty to a good print. During this process, stains occasionally appear, which are owing to the accidental presence of free nitrate of silver. This should have been prevented by the salt and soda bath; or they may have been caused by carelessness in touching the print with the fingers. As hyposulphite of soda is a cheap material, it is better to use a fresh solution for every fresh picture. This plan often prevents the production of stains, and generally insures good results.

It only remains that the print should be afterwards well cleansed from all hyposulphite of soda, which is done by placing it on the surface of clean water, and pouring a gentle stream on it for some time. The print is then left for an entire day in a vessel containing plenty of water, which should be occasionally changed. This having been effectually performed, the picture may be considered as permanently fixed.

5. *The Toning Process.*—We have as yet described what may be termed the ordinary process of printing: there, however, remain for us to mention various plans, by means of which the brilliancy of the positive may be increased. This is usually effected by means of a solution of chloride of gold. Great care is required to produce the best results; and the tyro must not expect, at a first trial, to arrive at perfection. For this reason we have deferred introducing the subject of toning until we supposed, by the practice of previous processes, some amount of proficiency had been acquired.

We need scarcely observe that none but really good positive pictures are worthy of the toning process; and more than this, they should have been printed with that object in view. In giving instructions as to this process, we cannot do better than quote from the *Photographic News* Almanac, in which the writer lucidly points out each step. We can confirm, from our own experience, the statements which he makes: and shall presume that our previous instructions as to sensitising the paper have been fully carried out. The author of the paper referred to, says:—

"The printing should be effected as soon after exciting the paper as possible: considerable over-printing is generally desirable. The lights should be of a delicate lavender tint, and the shadows deeply bronzed, before the print leaves the pressure frame.

"The prints should be washed in two or three changes of water just before toning; and the final washing-water may have a little salt added. Long soaking in salt and water renders the toning more difficult. All the processes in connection with printing and toning, with the exception of the exposure, should be conducted in the dark, or in yellow light; and the most scrupulous cleanliness, as to fingers and dishes, must be observed. In regard to the latter, it is desirable that each one be kept to its own purpose, and never used for any other; and the utmost care should be taken not to put the fingers which have just touched the hyposulphite of soda, into the gold solution.

"Several different forms of the alkaline gold toning bath have been proposed, all of which have been practised with more or less success. We shall only refer to those with the results of which we are familiar, and can speak with personal confidence. The first is the process of Mr. Maxwell Lyte, with which most photographers are already familiar. It stands thus:—

"Chloride of gold . . .	1 grain.
Phosphate of soda . .	18 grains.
Distilled water . . .	*quantum suff.*

"The chloride of gold, and phosphate of soda, should each be kept in solutions of given strength —say one grain of gold to an ounce of water; they can then be well mixed in any quantity required for use, and diluted with sufficient water to float the prints easily. The only effect of using a large quantity of water, is to make the process of toning somewhat slower, which is frequently an advantage. Sufficient water tends, moreover, to secure regular toning. The prints should be kept moving, and prevented from sticking together, or red, imperfectly-toned patches will be the result. The water used for diluting the bath may be previously made warm, as it materially facilitates the process.

"The process of toning is more rapid in some cases than others; but in most cases, a few minutes—from two minutes to ten—is sufficient. It is, in all cases, desirable to allow the print to assume a little deeper tint than is required in the finished picture, as a little will be lost in the hypo fixing bath. If a sepia or brown be required, a decided purple tint should be obtained in the toning bath. If a decided purple be desired, then the tint in the toning bath should be black.

"For the phosphate of soda, the bicarbonate or biborate may be substituted, but in less proportions, in regard to the carbonate especially, as an excess of it has a tendency to dissolve the size of the print, and, in some cases, even the albumen. Five grains will, therefore, be generally found sufficient; the only object being to neutralise the free acid in the chloride of gold.

"We have seen very fine prints produced by the toning process recommended by Legray; which is as follows:—

"Chloride of gold	1 grain.
Chloride of lime	1 grain.
Chloride of sodium (common salt)	1 grain.
Distilled water	4 ounces.

"The treatment is similar to the first-mentioned; but as there is a strong bleaching tendency, it is necessary that the prints be considerably over-printed.

"The last process of gold toning to which we shall refer, is one being the suggestion of M. L'Abbé Laborde. We may mention, however, that its advantage had been pointed out some months before by Mr. Hannaford, who states that a peculiarly rich purple bloom is secured, which is absent when any other salt of soda is used with the gold, with the exception of the citrate as proposed by Mr. Hardwich, which has a similar effect. Mr. Hannaford states that it has another advantage, which the Abbé confirms —namely, that it may be used more than once; all other alkaline toning baths being useless for toning purposes after once being used for toning. The formula stands as follows :—

"Chloride of gold	15 grains.
Acetate of soda	$7\frac{1}{2}$ drachms.
Water	35 ounces.

"The solution becomes colourless by degrees, and, at the expiration of twenty-four hours, it is ready for use. On removing the positive from the printing frame, it is washed in two or three waters, to remove the free nitrate of silver ; it is then immersed in the gold bath, where it must be allowed to remain not more than twenty-five to thirty seconds, when the bath is first used.

"If the gold bath has been used before, its action is slower. Experience will enable the operator to see, by the successive changes in tone the proof assumes, when he should remove it from the bath. If it be removed too soon, the proof assumes a disagreeable red hue after it is fixed with the hypo ; on the other hand, if it be allowed to remain too long in the gold bath, the proof assumes a cold blue tint. Between these two extremes there are a variety of tones of sepia and violet, which can be secured by removing the proof at the proper moment. In proportion to the length of time the gold bath has been used, so we must prolong the toning until the required tint appears. The strength of the gold bath can be restored by adding fresh chloride of gold ; but, before making the addition, we must take care that the solution is nearly colourless ; for if the chloride of gold is not in combination, it will, like other chlorides, weaken the proof.

"In all cases the prints should be washed in two or three changes of water, and then immersed in the hyposulphite of soda ; which, it is desirable, should possess a strength of at least twenty per cent., or four ounces to a pint of water. It is better used fresh each time, and should be neutral or slightly alkaline. Mr. Lyte recommends the addition of a little Spanish white, or chalk, for that purpose. Prints on thin paper are more rapidly fixed than those on thick ; but they should not, in any case, be removed from the fixing bath in a shorter time than ten minutes. They should then be washed in several plentiful changes of water, within the first half-hour ; and subsequently soaked and washed, so as to thoroughly remove all traces of hyposulphite of soda."

The preceding instructions will be of value to all who desire to produce the best results obtainable in the printing process ; and, as we have already observed, our own experiments affirm their useful and reliable character.

Having thus entered fully into the entire process of printing, etc., we trust that our readers will find no extraordinary difficulty in pursuing these experiments ; and we shall now pass on to consider a variety of photographic processes ; which, although not employed so universally as those we have minutely described —still, either afford interesting results, or, in an historical point of view, are not to be overlooked by us.

Photographing and Printing by Artificial Light.

Hitherto we have supposed that the light of the sun's rays alone has been employed in obtaining the various results described in the preceding pages. In the early part of this chapter we have entered largely on the philosophy of photography, so far as optical laws are concerned, and have pointed out some peculiar characteristics of that force. The reader, in perusing our remarks at page 620, *et seq.*, will find a full account of the nature of actinism and what are called actinic rays. Subsequently we have noticed some peculiar facts that are involved in the nature of the prismatic spectrum, and that enable us to employ what is called spectrum analysis.

Now, with these few exceptions, all our sources of artificial light are deficient in regard to actinic rays. The flame of ordinary gas, oils, paraffin, etc., are thus characterised, and consequently have little if any effect on a sensitised collodion plate. They are consequently useless as illuminating agents to the photographer. But there are other sources to which we may turn attention that are capable of acting on sensitive plates, the chief of which are as follows :—The electric light, the oxy-hydrogen or lime light, the magnesium light, and the light produced by the combustion of certain substances familiarly known as blue-fire in pyrotechny.

1. *The Electric Light.*—Formerly the voltaic battery was the sole method of getting the electric light. In our own experiments we used a powerful arrangement of fifty cells of Grove's battery, together with a modification of Duboscq's electric lamp. The cells were arranged in single series, and each platina exposed an active surface of twenty-eight square inches. The length of flame was about half an inch, and, as nearly as could be judged, about a quarter of an inch wide. No reflector was employed, and the sitter was placed at about three feet from the charcoal points. Ordinary collodionised plates, which, on an average, required from twenty to fifty seconds' exposure in the camera by daylight, were used ; the manipulation, etc., being identical with the usual mode pursued in daylight photography.

An equally good photograph was produced by an exposure to the electric light for about thirty

to forty seconds, so far as the intensity of the light and shade of a positive was concerned. But the same objection exists to such photographs as is found in the use of the electric light for illuminating purposes—namely, that of the excessive depth of light and shadows, all half tones seeming to be entirely lost.

To remedy this, we tried a variety of arrangements, but entirely without success. The face of the sitter presented a deadly or ghastly white appearance on the plate; whilst any shaded or dark part of the dress or skin was equally black. The picture itself was therefore divided into two appearances only, and was entirely deficient of pleasing expression. In no trial with a varying strength of the light did we succeed in tempering this excessive contrast of effect.

There is one essential difference between sun and artificial lights of all kinds. The rays of the latter all proceed from a point and diverge from it as a common centre. Now the rays of the sun are all parallel to each other, owing to the enormous size of that luminary compared with that of the earth. It will be evident that the exterior edges of any photograph taken by artificial light of any kind must therefore receive less light than the centre of the picture, and therefore that it is impossible to have anything like the effect on the plate that is afforded by sunlight, and no increase in the power of the artificial light would be of the slightest influence in remedying this defect. But in printing, as we shall presently see, this defect becomes, in some respect, an advantage to the photographer.

Of course the enormous expense and trouble involved in the employment of the voltaic battery, for the purpose of taking likenesses, rendered the attempt useless in a practical point of view. But the recent improvements of the dynamo-electric machine, fully described in a preceding chapter on the electric light, removes that objection, but still leaves the others that we have alluded to.

2. *The Oxy-hydrogen Light.*—Owing to a less amount of actinic rays in this light, the solarising effect is not so intense as that of the electric light. Longer time of exposure is required, even to the extent of one minute; depending, of course, on the sensitive nature of the plate.

3. *The Combustion of Phosphorus in Oxygen.*—By this plan a most intense light is produced; but owing to its short continuance, it is of little or no avail. The pictures are, however, softer than those produced by the means already referred to, and have a more intimate blending of light and shade. In the ordinary way of producing this light a large glass jar may be completely illuminated by it. The rays from the vessel pass in nearly parallel rays to the sensitive plate, and hence a nearer approximation to the effects of solar light may be obtained, than by the previously described methods.

4. *Moule's Photogenic Arrangement.*—Unaware of the late Mr. Moule's invention, we tried, in 1856, some experiments with a compound called blue-fire, composed of the following ingredients:—

Nitre	4 parts.
Sulphur	2 ,,
Sulphide of antimony . . .	1 part.

And found that a portrait, nearly equal to that obtained by daylight, can be produced. Mr. Moule, we believe, adopted some chemical compound similar to that we have named; but in addition he used a lamp, in which the substance was burned. Photographs taken by such means are very good, and well defined as regards half tones, etc. The process, however, has been rarely employed; and, so far as we know, has never been used commercially, having been confined chiefly to lecture-table purposes.

The electric and oxy-hydrogen lights, but especially the former, are of great value in certain circumstances. In many of the museums of this and other countries, there are objects which, from their size, etc., are necessarily placed in positions where sufficient daylight can scarcely impinge on them for the purposes of the photographer. In such cases, the electric light has been frequently employed with great success; and photographs of many interesting objects have been obtained. As the objections which exist to portraits taken thus are rather advantages when the pictures of inanimate articles are required, the electric and oxy-hydrogen lights afford the most eligible means of illumination in such cases.

5. *The Magnesium Light.*—When magnesium wire and ribbon were first cheaply produced, about 1855, it was expected that the photographer would have an excellent means of taking what were called night-photographs, and many lamps were invented for the purpose of making it available. But the method was really but a nine days' wonder. All attempts to make the light of practical value failed.

An amusing circumstance once occurred to us in regard to the use of the magnesium light while we were giving a public lecture on photography in 1857. The lights already described had been used before the audience, and, in its turn, came the magnesium light. The chairman, a gentleman well known and respected in the town, was chosen as the *corpus vile.* The photographer and his assistant we employed for the purpose, each held a lighted magnesium wire, one on either side of the camera, to illuminate the face. When the picture was developed, our friend was represented by *two* noses, each with its own shadow in addition; and as our friend's nasal organ was one of the largest size, the effect was ludicrous in the extreme.

The electric light is now largely employed for printing purposes, a dynamo-electric machine being adopted as a source of light. As already mentioned, no objection exists in this respect, on account of the rays proceeding from a point. In fact, this rather adds to the general effect, especially when pictures of busts, sculpture generally, flowers, etc., are concerned. Some of these, as produced in France, are beautifully executed, and frequently present, when magnified, a kind of stereoscopic effect to the eye, and the idea of solidity, rather than that of reflection from a plane surface.

Having just used the term "stereoscopic," we may pass on to make a few remarks on—

Stereoscopic Photography.

The stereoscope is so well known as not to require any particular description on our part. It gives to the eye the effect of solidity from two pictures, placed in a proper position, the images overlapping each other. The particular form of the instrument, used as a stereoscope, varies according to the fancy or method of construction of each maker; and into such we shall not enter, but rather confine ourselves to the mode of taking stereoscopic pictures, and the instrument required for that purpose.

In a single camera, the rays of light passing from an object to the ground-glass or sensitive plate, do so exactly as occurs when any object is seen by one eye. If another camera be placed next to the first, the rays will not fall exactly to the centre of its plate, because they arrive at two different angles from the source. Again, if an object, at a short distance from the eye of the observer, is viewed alternately by each eye, it will not appear in the same position as it would if viewed by both eyes simultaneously. The distance between the two eyes, of course, produces a separate angle of vision for each; and hence the right eye can see further to the left than can the left eye; and, *vice versâ*, the left eye can see more to the right of any object.

We cannot here enter into a disquisition on the laws of vision, but the subject is of great interest. We may, however, suggest a very simple experiment, which may be tried by any person having good sight, and of course in the possession of two eyes. Place a wine-bottle, corked, at some distance from the eyes, but level with them; in the cork fix a needle vertically, having another cork in the hand. Place the bottle so that the cork in it shall only be at a distance of five inches from the eyes. Close one and try to place the cork on the needle. Occasionally a little difficulty may be experienced in doing this. Now close the eye you have been looking with, and open the other, and try to place the cork on the needle. Owing to the difference of the angle of vision of the two eyes this may be at first a matter of difficulty. The experiment may be tried by removing the bottle to greater distances from the eyes, and some idea may be thus gained of the philosophy of the stereoscope.

Now stereoscopic pictures are always taken in duplicate, each at an angle varying with the other, as the angle of vision of the two eyes differs. It follows, therefore, that either two cameras must be employed, or that, if the picture is taken by a single-plate-taking camera, then the instrument must be successively placed at two different angles to take the picture in a proper manner. An inspection of any stereoscopic print will illustrate the remarks we have here made; for it will be found that one either exceeds or falls short of the other in the representation of the width of its field of view.

In practice, a double camera is always employed; for the operator, having the two instruments arranged permanently at the proper angle, has no trouble in the mechanical part of the process. Besides this advantage, the person desiring a likeness has not to undergo the fatigue of a double sitting, and the chance of placing the head and body in such a position as would be required to produce a second and corresponding one to that first procured by the single arrangement.

The entire manipulation, beyond the management of the camera, is exactly the same, in all respects, as that we have described under the collodion process; two plates being employed, or rather one plate, on which two pictures are produced.

The stereoscope has done much towards popularising the art of photography; and the favour with which the simple instrument was at first received by the public, induced the invention of a great variety of arrangements, by means of which a number of pictures may be successively viewed by one or more persons. The pictures are often mounted on an endless band, between two stereoscopes placed opposite to each other; and thus the number of pictures is limited only by the length of the band, or the size of the whole arrangement. A handle, affixed to the roller on which the band revolves, brings the objects successively in view to either stereoscope. The manufacture of single stereoscopes has been greatly improved in cases where magnifying power is added.

We have hitherto dealt with what we may call the standard processes in modern photography, subject to numerous modifications on the circumstances, choice, and, at times, we might almost say the whims of the operator. Great inconvenience has been felt by photographers, however, in taking views by the ordinary collodion process, owing to the necessity of exciting the plate immediately previous to its being introduced into the camera, and numerous attempts have been made to prepare plates which would retain their sensitive condition for a length of time after they have been excited. These have resulted more or less successfully, but they still leave room for improvement. It was at first proposed to use a salt which would deliquesce or absorb moisture from the atmosphere, and so retain the collodion surface in a proper condition for the camera. This plan was superseded by others, which seemed more convenient in practice. We shall describe some of these here, and subsequently describe improvements that have been more recently effected.

We shall first refer to what is called the collodio-albumen process. In following it the plates should be very carefully cleaned for this and all dry processes, and especial care taken that they are perfectly dry before coating with collodion. The quality of the collodion used is not of importance, so far as the question of sensitiveness is concerned; but for the better prevention of blisters, etc., an old or powdery collodion is desirable. The plate is coated and excited in the regular way, and washed thoroughly in a running stream, to remove free

nitrate of silver. It is then coated with a solution, prepared as follows:—

Albumen	. . . . . .	2 ounces.
Distilled water	. . . .	½ ounce.
Iodide of potassium	. . .	10 grains.
Bromide of potassium	. .	2 ,,
Liquid ammonia	. about	20 minims.

The iodide and bromide should be dissolved in the water, which should then, together with the ammonia, be added to the albumen, and the whole thoroughly beaten to a froth. When it has settled, the clear portion should be poured off, and kept in a bottle for use.

The washed collodion plate is to be coated with this whilst it is still wet. After it has drained a moment or two, pour over its surface the albumen twice. The same albumen may be used for two or three plates; but after that, it is better to take a fresh quantity. The plate must now drain on one corner a few minutes; then dry it rapidly before a clear, bright fire, and make it quite hot. In this state it is not sensitive to light, and will keep for many months. To render the plate sensitive for use, it must be again immersed in a bath, prepared as follows:—

Nitrate of silver	. . .	40 grains.
Glacial acetic acid	. . .	½ drachm.
Water	. . . .	1 ounce.

After taking the plate out of the bath, drain a moment, and then wash well under a stream of water. A plate well washed always keeps longer, and develops cleaner, than one washed insufficiently. After washing, drain, and place it on blotting-paper to dry. The plate may be dried artificially; but will do so spontaneously in about ten minutes.

The plates will keep ready for the camera two or three weeks in summer, and as many months in winter; but it is better to use them fresh.

The development of the latent image is the most important operation in this process. It is slow; but, on that account, very manageable. If the plate is well exposed, and free from blisters, there is no doubt of getting a picture. There are two methods of development: with pyrogallic acid and with gallic acid. To develop with pyrogallic acid, take the exposed plate, and place it on a levelling-stand; pour a little water over the surface; then take a sufficient quantity of the following developing solution:—

Pyrogallic acid	. . . . .	2 grains.
Glacial acetic acid	. . .	½ drachm.
Water	. . . .	1 ounce.

And pour it over the plate repeatedly. When the sky and high lights appear, add a few drops of a ten-grain solution of nitrate of silver. This will bring out all the details of the picture; but when held up to the light, it will appear weak and transparent. In this state more silver should be added, until sufficient intensity is gained.

During the development, it is more than probable that the surface may be marked by streaks or stains, or a deposit may cover the whole plate. If this should occur, stop the development; wash with water; and, with a piece of fine cotton wool, rub away these defects, and go on again with the development; the horny surface of the albumen allowing this to be done without fear of damaging the negative. This is the great advantage the process has over every other. The plate can be developed for hours or days; because, though a deposit falls, it can be wiped over and over again. This is an immense advantage when the picture is under-exposed, as it can be frequently brought out by long development.

To develop with gallic acid, take the exposed plate, and put it, face upwards, into a glass or other dish, with a sufficient quantity of a saturated solution of gallic acid to cover it. When it has remained five or ten minutes, add a few drops of a ten-grain silver solution, and mix well in the dish; the picture will gradually appear. When all the details are out, add more silver, till the development is complete.

Whichever process of development be adopted, great care is required to attain just the proper amount of intensity, and no more. In all processes where albumen is used, the real printing intensity is much greater than it at first appears, owing to the light-resisting colour of the deposit. There is great danger of over-development, as some photographers are not content until the sky is quite black; at which time, in an artistic point of view, the picture is quite ruined.

The picture is fixed with hyposulphite of soda, in the proportion of five or six ounces of the salt to the pint of water. Cyanide of potassium would act rapidly on the organic deposit, and is therefore unfit for use.

Another process was invented by Mr. Fothergill, which is so called after its inventor. The following directions are given for carrying on this process:—

"For coating the plates, take of old iodised collodion, containing one grain of a bromide, in addition to four of iodide, one part; and of a newly iodised collodion, containing iodide only, one part. The glasses (glass-plates) must be carefully cleaned, and quite dry when coated: a thirty-five grain nitrate bath, with a very slightly acid reaction, is the best sensitising solution. The plates, when excited, must be washed in a limited quantity of distilled water. A solution is then required, prepared as follows:—Of albumen, from fresh eggs, one ounce; of water, three ounces; of the strongest liquid ammonia, a few drops to each ounce of the preparation; and also a few grains of citric acid. The plate is coated with this preparation, which is left on it a few minutes; it is then to be thoroughly washed in water, and dried. Plates so prepared are very sensitive, and possess good keeping properties."

We have chosen the two processes above described because they are comparatively easy of prosecution. A variety of substances, of a vegetable kind, have been employed as preservatives: such as linseed, malt, glucose, etc.; also gelatine and other substances. But, as already stated, the subject will be again dealt with at a future page.

Our readers will perceive that many precautions have to be observed to ensure successful results; and their patience and perseverance

will doubtless be well tested. At the same time, a really good negative is an ample reward for all the pains we can bestow; whilst an inferior one is, at all times, valueless for printing purposes.

There are many processes in comparatively little use, among which we may instance the following:—

The Wax-Paper Process.—Amongst other materials which have been used as a photographic material, we may briefly notice that of waxed paper, which has the advantage of considerable sensitiveness, and of affording a pleasing effect when the picture is complete. This, like all other photographic processes, has been the subject of numerous modifications; and we shall, therefore, only give a general outline of it.

A thin kind of paper is to be soaked in the best melted white wax, until that substance is well absorbed into its pores. The waxed paper is then placed between folds of blotting-paper, and a hot iron is passed over the whole, so that the wax may be equally diffused, and any superfluity be removed. The paper, so prepared, is next placed in a bath of iodide of potassium, to which a little iodine has been added; and, after remaining some time, it is carefully dried. It is sensitised by means of a weak nitrate of silver bath, to which some acetic acid has been added; and if thus dried, it will keep for some time, provided it has been well washed with distilled water, to remove the superfluous nitrate from its surface.

The length of exposure in the camera varies from one minute upwards; and the latent picture is developed by means of gallic acid and nitrate of silver. The fixing is effected by a solution of the hyposulphite of sodium, and subsequent repeated washings in water. The picture may then be dried before a fire, and a hot iron should again be passed over it to equalise the wax in each part of the paper.

This plan is not much employed at the present time; and, like most others, has been superseded by the collodion and gelatine processes.

The Chromotype Process.—This process is so easily conducted as to be at the command of any one, however slightly acquainted with science or experimental manipulation. It depends on the fact that certain salts of chromic acid are easily acted on by actinic rays; and the most proper for the purpose is the bichromate of potass.

A saturated solution of this salt is made in cold water, in which any suitable-sized sheet of paper may be immersed. The salt will soon penetrate its pores; and the paper, after draining, is to be dried between folds of common blotting-paper. It will thus have acquired an orange-yellow tint, and it may be preserved for any length of time if kept in a dark place. It is used in exactly the same way as the positive paper (described at a previous page) in the copying frame. The object is placed on the plate-glass: on this the chromatised paper; and the back of the frame is then fitted into its place; or the object may be simply kept in contact with the prepared paper, by means of a heavy sheet of plate-glass.

The time required for exposure, of course, varies according to the chemical power of the daylight. The exposed parts should, however, present a dark-brown tint before the object is to be removed.

The process of fixing is remarkably simple. The picture is soaked for some time in warm water, so as to dissolve out any unchanged bichromate of potass. The paper will thus be rendered nearly white, or, at all events, of a light primrose colour, in those parts which have been shaded by the object copied; whilst the other parts present a dark-brown hue.

This process may be readily employed for copying any object whose outlines are well defined—such as lace, ferns, the shape of leaves, etc. Indeed, with a child's transparent slate, and a few sheets of paper, the botanist, and others, may copy a vast variety of objects; and, from the simplicity of the whole affair, it may afford an instructive and interesting amusement to young people.

Photographic Engraving.

A careful perusal of the preceding pages cannot fail to impress on the reader, whether scientific or not, the importance that the art of photography possesses in the power which it affords us of reproducing in every detail the exact appearance which any object that is capable of being copied by photography presents. Criminally this power has been, together with that afforded by the electrotype, applied in multiplying bank-notes, and in forging them, cheques, and other securities. But in the legitimate application of the art this exact reproductive power has had many applications. It is true that we have not yet succeeded in making light its own engraver, at least with one exception, that of the invention of M. Paul Pretsch, to which we shall presently call attention. But great advances have been made, and past successes may lead us to hope for further in the future.

The usual process of copying from negatives is necessarily somewhat slow, and therefore greatly limits the production of paper positives. A great variety of attempts has accordingly been made, the object of which has been to produce blocks, on which photographic pictures could be engraved, and printed from.

Some of the earliest experiments for this purpose were made on Daguerreotype plates. These were etched out by chemical means, or electrotyped, so as to present an uneven surface, which would afford the effects of light and shade when engraved from.

One of the best prints which was made by this process, was produced many years ago, by Mr. Grove (now one of the English judges), at the London Institution; being an outline of that building, obtained from a Daguerreotype. We had an opportunity of carefully examining one of these, but the result was not pleasing, and much resembled an ordinary etching in outline only.

Mr. Fox Talbot, and others since then, made

considerable advance in this department of photographic practice. Pictures have been transferred to stone and wood; and, from these, engravings have been produced. But one of the most important successes that have been attained was in the invention of the photozincographic process, of which the following is a description, extracted from the *Photographic News*, given shortly after the invention came into use:—

"*The Photozincographic Process.*—The most successful method of carbon printing is that perfected by Colonel Sir Henry James, R.E., Director of the Ordnance Survey of Great Britain, which has led to the most important results, both in an artistic and economical point of view. The singular advantage which this art possesses, consists in the fact that we can now produce authentic copies of any of the numerous rare manuscripts, which are carefully preserved in different parts of the world; and print any number of copies of them that may be required, at a cost which will not exceed one penny for a folio sheet, and this without ever touching the original document; or, if required, without even being in the same room with it, provided we have a hole in the wall, to place the lens of the camera in.

"Photozincography is the name given to this process, which is the art of producing a photographic *fac simile* of any subject; such as a manuscript, a map, a line engraving, and transferring the photograph to a zinc plate; thereby obtaining the power of multiplying copies in the same manner as is done from a drawing on a lithographic stone, or on a zinc plate.

"The process is based on that first suggested by M. Aser, of Amsterdam; viz., the obtaining a photographic picture on paper prepared with the bichromate of potass (see *ante*, p. 659, under the head of the Chromotype process); washing off the unchanged salt; inking the image left on the paper with photographic ink; and then transferring the same to a prepared zinc plate, from which any number of impressions may be printed.

"The steps to be taken to obtain this important result, are—first, to produce a collodion negative on glass, in the usual manner, of the document to be copied; this negative may be identical in size with the original, or larger or smaller, as may be most desirable. The greatest care is required in obtaining this negative perfect, as any defects it may contain will necessarily be reproduced in the copies. The lenses employed must be in due relation with the size of the object copied, so as to avoid distortion.

"The negative will require to be intensified, in order that whiteness of the paper may be reproduced in the positive. This intensity is readily obtained by immersing the fixed negative in a saturated solution of bichloride of mercury, washing it with water, and then putting it into a solution of commercial hydrosulphate of ammonia—one part to ten parts of water.

"In this manner the ground of the negative is rendered extremely dense, without the clearness of the details being in the least affected. When dried and varnished it is ready for use.

"With this negative we proceed to obtain positives on paper. The quality of this paper is a point of much importance; the best is that known as 'engravers' tracing-paper.'

"A solution of gum-arabic is made by dissolving three ounces of the gum in four ounces of water.

"Boiling water is saturated with bichromate of potass; and two parts of the solution is mixed with one part of the gum-water, both being kept at a temperature of 200° Fah.

"The tracing-paper is evenly coated with the hot mixture, by means of a flat camel-hair brush, and dried; it is then exposed to light, under the negative, in the usual way. The time for printing may vary from two minutes in the sunshine, to ten minutes in clear diffused light. If a good image is not obtained in that length of time, the operation had better be deferred to a more favourable opportunity. The period of exposure is determined by the appearance of the print; when all the details have become distinctly impressed, it may be removed.

"The next thing is to coat the entire surface of the print with an even and thin layer of a greasy ink, which may be composed of the following ingredients:—

"Middle linseed oil varnish .	4½ ounces.
Wax	4 ,,
Tallow	½ ounce.
Venice turpentine	½ ,,
Mastic resin	¼ ,,
Lampblack	3½ ounces.

"A portion of these is dissolved in turpentine sufficient to form a thin cream, which is applied to the surface of the positive print with a brush.

"The turpentine is allowed to evaporate for half-an-hour, and the positive is then floated, face upwards, on hot water for a few minutes; then removed, and laid, in the same position, on a porcelain slab.

"The surface is then gently rubbed with a sponge, dipped in warm gum-water, when the ink readily leaves the surface at those parts which have been unacted on by light; while it adheres tenaciously to the details of the image.

"As soon as the lines are quite clear, the print is placed on a flat dish, and washed, first with warm, and finally with cold water. When dry, it is ready for transferring to zinc or stone.

"There are two methods of transferring to zinc, varying according to the quantity of ink in the photograph.

"If a very small quantity has been applied on account of the closeness of the lines in the subject, the print is transferred by the anastatic process.

"If a larger quantity of ink has been applied, the process is different.

"The positive is laid for ten minutes between sheets of paper, damped as uniformly as possible with water; it is then laid face downwards on the plate, covered with two or three sheets of paper, and passed once through an ordinary lithographic press. The sheets of paper being removed, it is damped at the back with gum-water, till its adhesion to the plate is so lessened

that it can easily be pulled off. After the transfer has been gummed, brought up, and etched, the ink is cleared off with turpentine, and the design is rolled up with printing-ink. Impressions can then be taken from it.

"The quantity of ink necessary to be applied to a photographic positive, to make a successful transfer to grained zinc, is greater than that which is necessary for stone; and the anastatic process requires the least of all.

"The action of the warm water in which the positive is immersed on the insoluble gum, is to cause it to swell; and the ink which overlies the lines formed of insoluble gum, expands likewise. It is evident, therefore, that if the subject photographed be of a close nature—as a fine engraving—the amount of enlargement of the inked lines may be sufficient to bring them into contact while the print is in the water; and when they have once coalesced, they will not separate again when the gum shrinks in drying, and there will consequently be a continuous shade of ink instead of lines. In such a case, the quantity of ink applied should be as small as possible; and to enable a light but even coating to be laid on it, must be thin. As a consequence of the small quantity of ink used, the transfer must be made on a smooth plate by the anastatic process; because, to make a successful transfer to a grained plate or stone, a larger quantity of ink is necessary. On the other hand, as impressions taken from a grained plate or from stone, are, as a rule, better than those from a smooth plate, and as a larger number of good impressions can be struck off if the subject photographed be so open that there does not appear to be any likelihood of the lines coalescing in the water, it is better to apply the ink in greater proportion to the print, as a certain quantity is indispensable for the employment of the latter mode of transfer. By the application of this process to the reduction of the plans of the Ordnance survey, an immense saving of time is effected; while the total money saving will amount to no less a sum than £35,000 on the cost of the survey."

Having thus given our readers the above account of the photozincographic process, we shall now proceed to describe that of M. Paul Pretsch; which, as already observed, we have repeatedly examined in all its details.

Engraving by Light and Electricity.—Under this title or term an invention was brought out in 1855 or 1856, by M. Paul Pretsch, formerly manager of the Imperial Press at Vienna. Its object was solely to employ light and electricity for the purpose of engraving and producing copper plates for the printer, so that he may employ them in the manner usually adopted with those engraved by hand after the ordinary method of copper-plate production for illustrations, etc.

In 1856, M. Pretsch kindly favoured us with full instructions for pursuing personally his method, which we found no difficulty in doing, with the exercise of ordinary care. As will be seen, the invention is of a most ingenious character, and in one part somewhat resembles that just described, namely, in the use of bichromate of potass, and the employment of an elastic substance; M. Pretsch, however, preferring glue or gelatine to gum, used in Sir Henry James's zincographic process. The following is an outline of the method adopted by M. Pretsch.

The inventor avails himself of the fact that animal matter, combined with bichromate of potass, is peculiarly acted on by light, and becomes thereby considerably hardened. A mixture of good glue or gelatine is made with a solution of bichromate of potass, aided by the application of heat. It is of such a consistency as to become solid when cool. We have found that when cool the gelatine should not have less firmness than that ordinarily sold in the form of lozenges, and indeed firmer if possible. Whilst in the liquid state, solutions of nitrate of silver and iodide of potassium are added to it; and after the whole has been well incorporated together, the liquid is poured on to a clean glass plate, and allowed to cool in a dark place.

Presuming that an engraving is to be copied, it is to be placed, face downwards, on one of these prepared plates, and pressed closely on the glued surface, which must not have anything like a sticky surface. This is best effected by the copying frame referred to and illustrated at p. 653, *ante*. It is then to be exposed in the usual manner, varying from a few hours in direct sunlight, to a day or two in diffused light. On removing the plate from the frame, it will present no great visible change, or, at all events, its surface will still be perfectly level, even if some effect of shadowed outlines may be perceived, which we have generally noticed. It is then to be immersed in water, or, as the inventor recommends, a solution of common salt in water. An immediate effect takes place; those parts which have been exposed to solar action retain their previous condition; whilst those which have been shaded by the dark part of the engraving from the action of light, immediately rise up beyond the ordinary level, and form a series of *raised* lines, exactly resembling the shaded lines in the original. The glue surface, therefore, assumes exactly the opposite condition of that of an engraved plate in which the shaded portions are *hollow* lines. The plate is then dried; and when again each part has become firm, a cast is taken from it by means of any suitable substance, such as plaster of Paris, which, of course, produces an *intaglio* impression. From this a cast is taken by means of gutta-percha, etc., which becomes the mould, from which a solid engraved copper plate may be obtained. For this purpose the electrotype process is employed. In the article on Electro-Metallurgy full directions for this purpose have already been given at page 284, *et seq.*, of the present volume.

In the course of twenty-four hours a complete copper copy of the mould taken from the gelatine plate will be produced. This electrotype is gently removed from the face of the mould, after both have been taken out of the depositing solution. Its edges are then trimmed, and it is at once ready to be employed in the printing-press, in exactly the same manner as is ordinarily adopted in copper-plate printing.

It will be perceived that, by this curious process, a complete and perfect engraved copper-plate may be produced by the sole action of light and electricity; and viewed in a philosophical point of view, it presents one of the most interesting applications of two forces with which we are acquainted.

For the sake of simplicity, we have only supposed the case of the copying of an engraving. Photographs, etc., can, however, be easily reproduced by the same means; and thus an exact copy of any object can be almost indefinitely produced. The inventor, however, finds that, owing to the softness of copper deposited by the electrotype process, not more than six or eight hundred copies can be printed from one plate. Any number of plates, however, may be produced from the original mould. We have seen numerous specimens of engravings so procured; and have no hesitation in pronouncing them to be of the greatest accuracy and perfection in their detail and general effect. The ingenious inventor has applied the process to a variety of purposes; amongst which we may mention that of producing engravings from personal photographs; by means of which, linen or cotton may be marked with the likeness of the owner, instead of by the ordinary plan of marking-ink. Our readers of the fair sex will instantly appreciate this application, because it prevents that constant interchange of the ownership of property, to which the laundry-women of our large towns are so prone. Similarity of initials is common enough; but a photograph on wearing apparel at once stamps an unerring title as to the proper right of possession. Ingenious, however, as the invention is, it has never been put into practical use.

Microscopic Photography.

Some very interesting results have been obtained by applying the photographic process to obtaining pictures of microscopic objects. This is easily effected by receiving, either through or without the eye-piece of an achromatic compound microscope, the image of the object on a plate by means of the usual collodion process. In fact, the lenses of the microscope answer in place of the lens of the camera: the plate, however, must be so arranged as to be entirely protected from external light. This is easily done by placing it in a small dark box at the end of the eye-piece, from which the image proceeds to the prepared plate.

Such pictures can afterwards be submitted to the microscope, and may of course be magnified to any desired extent. One great advantage arising from this use of photography is, that perishable objects can be copied exactly as they appear at any moment, and so all their peculiarities of construction or constitution may be permanently retained; and if negatives are taken, any number of copies can be subsequently produced either on glass or paper.

Perhaps the most interesting kind of photographs of this kind, are those which have been taken of the blood globules of animals. We believe that these were first exhibited by M. Duboscq, of Paris, at a meeting of the British Association about 1856, at Glasgow. Since then, an immense variety of microscopic photographs have been produced; and they are now a common article of sale at the optician's, etc.

Colouring Photographs.

We regret to say that all attempts to obtain pictures with natural colours, by means of photography, have, as yet, been unsuccessful. The photographic artist has, therefore, endeavoured to supply this want by applying colours to photographs, and so producing a picture resembling that produced by the painter.

The practice was first commenced with Daguerreotypes, which, from their heavy metallic hue, were anything but flattering likenesses in many cases. After the collodion process was introduced, the art of colouring was still more largely practised, and has now arrived, in many instances, at a high artistic rank; although, when in the hands of the majority of those who employ it, the results are scarcely better than hideous daubs, in which the value (if any) of the photograph is entirely concealed, and its defects strongly magnified.

The colours, in a state of impalpable powder, are applied by means of a camel-hair pencil, moistened with a little water. Some highly-finished oil portraits have been produced by leading photographers; which have the advantage of being exact likenesses, together with that peculiarly pleasing expression which the taste of a thorough artist can alone give.

We have frequently employed photography for another purpose, to which we will refer; and our remarks may be useful to the managers of Mechanics' Institutions, etc. The ordinary mode of producing dissolving views is that of first sketching on glass by means of Indian ink, and then of filling up the outlines with transparent colours. Instead of this plan, we have had portraits and landscapes first photographed, and afterwards coloured by the artist. The result is a pleasing and accurate picture, which, when magnified by means of the dissolving views or magic lantern, presents an exact illustration of any object on the screen. We have employed magnifying powers, varying from one to sixteen thousand times superficial, and can strongly recommend the plan to all who are desirous of having sets of views painted.

Care must be taken that the colours employed are quite transparent; that the collodion film is not too thick; and it is also essential that the lenses of the lanterns should be as free as possible from spherical aberration. The effects of this are avoided by the artist, as he paints all straight lines at a slight curvature; of course this is not allowed for in the photograph, which strictly represents objects as they actually appear.

A beautiful application of coloured photographs is now made of natural objects, to which we have already alluded when speaking of the application of the electric light to photography at page 656, *ante*. A positive being printed on

paper by the electric light, is next coloured by hand, in water colours. The result is very effective, and now a matter of ordinary sale at stationers', etc., in the form of birthday gifts, presents, etc., etc.

Photographic Registration.

Amongst the various uses to which photography has been applied, is that of registering magnetic, astronomical, barometrical, and other observations. As each of its applications is made in a form suitable to the instrument, the indications of which have to be noted, we shall confine our remarks to the explanation of the general plan, rather than to separate details.

A piece of paper rendered sensitive to the action of light by any of the processes mentioned in the previous pages is fixed round a cylinder. This is moved by clock-work, so as to rotate once in twelve or twenty-four hours; and the paper is divided into parts, so that each hour or part of an hour is marked on its surface. The whole is excluded from light, except at a small aperture, through which the rays of a lamp, concentrated by means of a reflector, alone can pass. Now the light so admitted will at once act on the paper opposed thereto; and as the paper is continually revolving as the day passes on, any ray falling on the surface will produce a black mark at a place on the paper, indicating the time of day.

When the paper is removed, a long and irregular line will be observed on the surface; and the position of this line will thus indicate—say the vibration of a magnetic needle, the rise or fall of the mercury in the barometer tube, etc., according to the mechanical and other arrangements to which it has been adapted.

It will be at once seen that this plan is of the greatest possible value to the philosopher. Day or night, the registration can be carried on with the most extreme accuracy; no chance of error need creep in if proper precautions are taken; and the results, printed by the hand of nature, are permanent, and not like the efforts of the human mind, which are intermittent from the necessity of rest, or uncertain from their infirmity. The plan is extensively employed in most of the public and private observatories of our own and other countries.

Celestial Photography.

One of the most surprising achievements of modern science is that of taking views of the heavenly bodies; which, in the case of the moon, are so accurate as to permit our tracing the valleys and mountains represented on photographs of her surface. The difficulty incident to such attempts will be better estimated when we compare the perfect stillness required of a person sitting for a likeness, with the circumstances which have to be allowed for in celestial photography. Some of these we may name, in connection with lunar photography. In the first place, the earth is rotating on its axis, at the rate of 1,000 miles per hour, in a westerly direction. At the same time we are travelling through space at a rapid rate. The moon, again, is revolving round the earth at the rate of about 2,000 miles per hour, in an easterly direction. The difficulty, therefore, at once presents itself, as to how sufficient absence of motion, or its equivalent, can be obtained for a few seconds of time. This is managed by so arranging the telescope, etc., by means of clockwork, as that it shall travel an angular distance equal to that traversed by the heavenly body in any space of time.

Our readers will understand the principle of this if we afford them a familiar illustration. We will suppose the case of a steam-boat in motion, towards which a telescope is being pointed by an observer on shore. The instrument, if gradually shifted, will apparently present the steamer to the eye at a state of rest; and the angular motion of the telescope will require to be less, exactly in proportion to the distance of the steam-boat.

Now the heavenly bodies are in a similar position; and as we know the exact rate of their and our own passage through space, it becomes a matter of pure mechanical arrangement to accommodate the angular motion of our instruments to them. This is done by means of clockwork; and the arrangements now employed have afforded some very interesting results.

Among instances of this application of photography, we may mention that effected during the solar eclipse of the 18th July, 1860. To those of our readers who are unacquainted with astronomy, we may explain that some peculiar appearances which are presented during an eclipse of the sun have afforded matter of deep discussion on the part of astronomers. Of these the beads, red flames, etc., which are frequently seen in an annular or total eclipse, are the most prominent. The intense excitement which naturally affects the coolest observer when phenomena of the deepest interest, and lasting but a few seconds of time, take place, is enough to unfit any one for taking accurate observations. Besides this, the power and peculiarities of vision of each person so engaged vary to so great an extent as to give an entirely different complexion to the observations taken. Photography here, therefore, steps in. The inanimate paper is subject to no emotion or disturbing cause, and it affords a ready and efficient means of registering an observation, which cannot possibly be otherwise than accurate.

For the purpose of obtaining varied and positive results, some of the leading philosophers of our time betook themselves to various places over which the shadow of the moon would pass. They were abundantly provided with instruments for ordinary and photographic observation; and when possible, the duties of observing were divided amongst a number of persons, so that each might make one phenomenon his special duty to attend to. We must confine ourselves entirely to the photographic results; and are indebted for such to the *Photographic News* Almanac, from which the following extracts have been made:—

"M. Foucault studied the corona, both optically and photographically. Immediately after the disappearance of the last solar ray of direct light, a prepared plate was exposed ten seconds; then a second plate was exposed twenty seconds; and lastly, a third plate was exposed during sixty seconds: they were developed by sulphate of iron, and fixed with cyanide of potassium, with the object of obtaining direct positives. Owing to a vibration accidentally given to the apparatus, four images were impressed on the first sensitive plate, in a very short space of time; three at least in less than a quarter of a second each: these possessed a peculiar interest and value; they did not give a complete picture of the aureola, but only of a circumference of the circle surrounding the obscure disc of the moon. On the side where the interior contact took place, the circular contour presented greater intensity, which confirmed the impression entertained by M. Leverrier. Irregularities, similarly situated, on these three images were remarked, which appeared to be an exaggerated representation of the lunar contour. When the proofs were placed in the actual position of the planets, it was seen that among the indentations two were principal and contiguous, situated at the inferior and eastern extremity of a diameter inclined at forty-five degrees. The three other proofs gave an extension to the aureola, which increased with the duration of the exposure. The aureola diminished in proportion as it receded from the planet, and its line of demarcation became lost in the tint of the ground which represented the sky. In the proof exposed sixty seconds, the aureola extended sensibly to a distance equal to thrice the radius of the central disc. But, in certain particular directions, the aureola exhibited positive and negative variations in its intensity, producing the representation of a glory. One of them, better defined than the other, was prolonged, in all the proofs, beyond the rest of the aureola, and seemed to emanate exactly from the point occupied by the indentation on the edge of the moon, already described.

"Such are the results of an experiment undertaken solely to ascertain the photogenic activity of the aureola on wet collodion. The harmony prevailing among the six proofs supplies positive elements for the discussion of the nature of the aureola."

The Astronomer Royal, Dr. Airy, proceeded to Spain; and the following contains the substance of a paper read by him before the British Association, at the meeting held in Manchester, in September, 1861.

In the early part of his discourse, Dr. Airy gave a general account of the cause and phenomena of eclipses; entering into a great variety of astronomical data, which it would be foreign to our purpose to repeat. Having disposed of the general nature of eclipses, he called attention to some peculiar appearances, termed "Baily's Beads"—a number of bright spots which have been noticed on the edge of the sun just before an eclipse became total. In 1842, red flames were noticed as protuberances from the edge of the sun; but the surprise and unprepared state of the spectators unfitted them to make accurate observations or detailed reports. In 1850, during a solar eclipse, similar, and additional, phenomena were noticed; and due preparation having been made to observe the same in 1851, several philosophers, including Dr. Airy, proceeded to Sweden, and other places, for the purpose of making a fresh series of observations. A variety of interesting results were obtained; but still the uncertainty of human power, and the mental excitement under which all the observers suffered, invalidated any conclusions at which they arrived, and still left much to be desired in the way of truthful result.

Accordingly, in 1860, a large party of astronomers, and others, proceeded from this country to Spain, well provided with apparatus of all kinds, and also with a complete set of instruments, by means of which the photographic art was put into full operation; and the entire proceedings were attended with the greatest success. Similar arrangements of clockwork, to which we have already alluded, were employed, and an accuracy of result was obtained which left scarce anything to be desired.

Amongst the most successful of the operations were those by Mr. De la Rue; which he conducted by means of apparatus he had arranged specially for the purpose. The annexed engraving represents a photograph of the eclipse

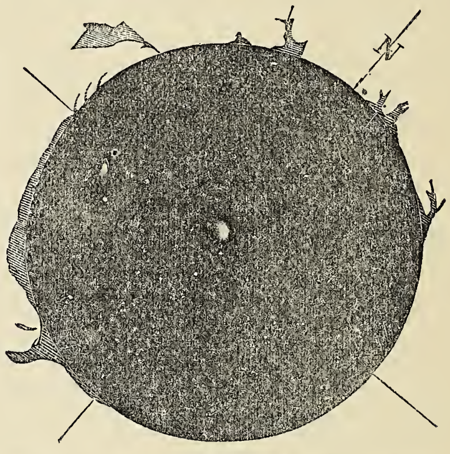


Fig. 344.—Photograph of an Eclipse of the Sun.

at its totality, and the red flames issuing from the outer edge of the sun.

The photographs thus taken were subsequently compared with those effected by other operators, and their exact similarity was so great as to prove the extreme value of photography in its application to astronomical observations. Indeed, many occurrences unperceived by the observer were thus registered, and additional light was thrown on a variety of previously obscure phenomena.

We have selected the previous instances of the use of photography in astronomical observations, simply to show what a valuable adjunct the art has been to high-class scientific investi-

gations. Photography has been similarly used in subsequent eclipses, and many interesting facts have thus been put into the hands of the astronomer.

Celestial photography will, without doubt, become still more valuable as improvements are made in the construction of telescopes. Recently, instruments of this kind have been made which as much exceed in value, that is the power of observation afforded, the great telescope of the late Earl of Rosse, as that instrument exceeded in its powers the telescopes of Herschel, and other astronomers of his period. We can already discern, distinctly, on the surface of the moon, an area of a few square yards, and there does not seem any very powerful reason, whether of astronomical or mechanical difficulty, why that area should not be reduced to square feet, or, at all events, what difficulties exist are not insuperable.

Photographing Comets.

We have already noticed, in connection with Celestial Photography, the fact that spectrum analysis has been of great use, combined with photography, in a scientific point of view. In the earlier part of this chapter we have given an outline of the principles on which spectrum analysis depends. One of its most interesting applications has been that of really analysing the chemical constitution of the heavenly bodies; and one of the latest contributions to this department of science is a paper which was read by Dr. William Huggins, F.R.S., at the meeting of the British Association at York, in 1881, "On the Photographic Spectrum of the Comet *b*, 1881." The author remarked as follows :—

"In the years 1866 and 1868 I applied the spectroscope to the light of comets, and in the latter year I showed that the three bright bands in the visible part of the spectrum agree with the similar bright bands which are seen when an induction spark is taken in olefiant gas. The same bands are also seen in the flames of many compounds of carbon. I was inclined at that time to consider that these bands were due to the vapour of carbon. Subsequent investigations which have been made on the spectra of the compounds of carbon appear to make it probable that these bands are the spectrum of a compound of carbon with hydrogen. These observations (1868) showed the presence of carbon—probably in combination with hydrogen —in the cometary matter.

"Since that time until the present year (1881) no comet has appeared sufficiently bright to allow of the observations on its spectrum being extended to the ultra-violet region. The apparatus with which I had successfully photographed the spectra of stars was especially suited to this purpose. It consists essentially of a spectroscope, furnished with a prism of Iceland spar and bases of quartz, placed so that the slit shall be in the principal focus of a mirror eighteen inches in diameter, equatorially mounted, and driven by an electrically-controlled clock.

"On the evening of June 24, 1881, I directed this instrument, armed with a very sensitive gelatine plate, to the head of Comet '*b*,' so that the nucleus should be upon one-half of the slit. After an exposure of one hour the open half of the slit was closed, the shutter withdrawn from the other half, and the instrument was then directed to Arcturus for fifteen minutes.

"After development the plate presented a very distinct spectrum of the comet, together with that of the star, for comparison.

"The spectrum of the comet consists of two spectra superposed upon each other :—A continuous spectrum, which extends from about F to a little distance beyond H. In this continuous spectrum can be seen the Fraunhofer lines G, *h*, H, and many others (see Fig. 345). This spectrum is, therefore, due to reflected solar light. The second spectrum consists of two sets of bright lines and a suspicion of the presence of a third set. These lines are obviously to be referred to original light from the comet.

"The strongest set consists of two bright lines in the commencement of the ultra-violet region. Measures, made by the aid of the comparison star-spectrum, give for these bright lines the wave-lengths 3883 and 3870. The less refrangible line is much stronger, and a faint luminosity can be traced from it to a little beyond the second line 3870. There can be, therefore, no doubt that these lines represent the brightest end of the ultra-violet group which appears under certain circumstances in the spectra of the compounds of carbon. Professors Liveing and Dewar have found, for the strong line at the beginning of the group, the wave-length 3882·7, and for the second line 3870·5.

"I am also able to see upon the continuous solar spectrum a distinct, though fainter, impression of a group of lines between G and *h*. There can be little doubt that this group is the one for the least refrangible limit of which the wave-length 4220 is given by Professors Liveing and Dewar.

"An increase of brightness in the continuous spectrum is also seen between *h* and H, which may be due to other bright lines; but the photograph is not strong enough to admit of any certain conclusion on this point.

"On June 25th a second photograph was obtained with an exposure of an hour and a-half. This photograph, notwithstanding the longer exposure, is fainter, but shows distinctly the bright lines in the ultra-violet and the continuous spectrum.

"These photographs confirm the results of my earlier observations on comets—that part of their light is reflected sunlight, and part is original light; and, further, that carbon is present in the cometary matter.

"The new bright groups in the comet's spectrum which the photographs have revealed to us are certainly characteristic of substances containing carbon.

"In their paper *On the Spectra of the Compounds of Carbon* (*Proc. Roy. Soc.*, vol. xx., p. 494), Professors Liveing and Dewar bring for-

ward evidence to show that these two groups indicate the presence of cyanogen, and are not to be seen in hydrocarbons unless nitrogen is also present. If this be the case, the photograph supplies us with strong evidence of the presence of nitrogen in the comet, in addition to the carbon and hydrogen shown to be there

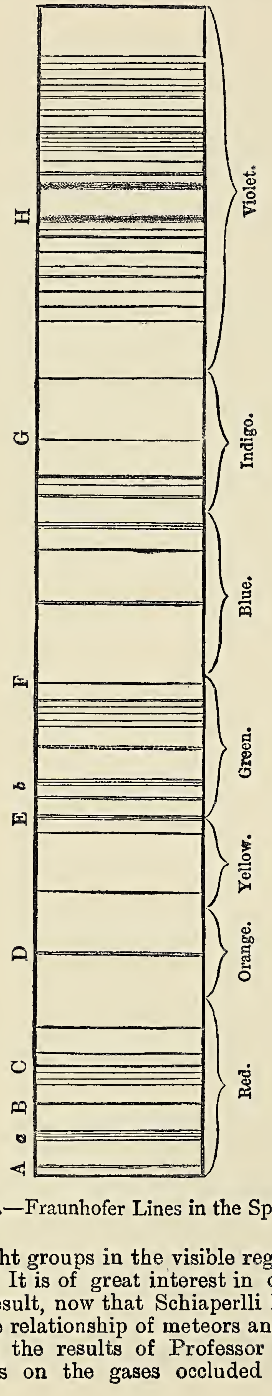


Fig. 345.—Fraunhofer Lines in the Spectrum.

by the bright groups in the visible region of the spectrum. It is of great interest in connection with this result, now that Schiaperlli has shown us the close relationship of meteors and comets, to mention the results of Professor Graham's experiments on the gases occluded from the meteoric iron of Lenarto (*Proc. Roy. Soc.*, vol. xv., p. 502, 1867). This iron gave nearly three times its volume of gas, consisting chiefly of hydrogen, with small quantities of carbonic oxide and nitrogen.

"Professor Wright's examination of the stony meteorites shows the oxides of carbon, chiefly the dioxide, to be present in largest quantity; but he obtained also a small percentage of hydrogen and nitrogen (*Amer. Journ. Science*, vol. x., July, 1875).

"Other kinds of meteors are known which contain hydrocarbons, even in considerable quantity. It is scarcely necessary to add that, under suitable conditions, the spectra of the gases from meteorites will be similar to that observed from the light of comets.

"Professors Liveing and Dewar's experiments would seem to show that a high temperature must be present in the comet if the cyanogen is formed there; but if cyanides should be found in meteorites the necessity would not exist.

"Whatever the views that may be entertained as to the forms of combination in which the carbon exists, there can be no doubt whatever of the presence of carbon in comets. I should mention that Mr. Lockyer regards the two bright groups seen in the photograph, and the three groups in the visible spectrum, to be due to the vapour of carbon at different heat levels (*Proc. Roy. Soc.*, vol. xxx., p. 461).

"It is of importance to mention the strong intensity in the photograph of the lines 3883 and 3870 as compared with the continuous spectrum, and the faint bright group beginning at 4220. At this part of the spectrum, therefore, the light emitted by the cometary matter exceeded by many times the reflected solar light.

"On August 21st I attempted to obtain, with an exposure of one hour, a photograph of the spectrum of a large comet which has appeared since—Comet '*c*,' 1881. The evening was not very favourable, and the comet was at a low altitude, and not so brilliant as Comet '*b*.' I am not able to see on the plate more than a faint trace of the brightest lines (W. C. 3883 and 3870) of the spectrum obtained from the former comet."

In an astronomical point of view, it is impossible to overrate the importance of the observations here related by Dr. Huggins. The nature of comets has long been a subject of speculation on the part of physicists, and certainly some ridiculous theories have been brought out to account for their character and existence. The prominence of two of the comets in the heavens which appeared in 1881, led to many theories being propounded to satisfy popular curiosity, but these left the matter just where they found it. The photo-spectral observations of Dr. Huggins have, however, thrown great light on these mysterious but curious questions of the constitution of cometary bodies.

We may here add that Dr. Huggins has succeeded in getting photographs of the spectrum of some of the fixed stars, such as Sirius or the Dog Star, Vega, Arcturus, Capella, and Aldebaran.

Telegraphic Photography.

In an age of wonders, when by means of the telephone and microphone we can converse with friends miles away, who hear distinctly our voices, and reply to us so that we may hear them in theirs, it would seem that we had almost arrived, like Alexander of old, at the end of all possible conquest and discovery. But such is not the case. In the preceding pages of this Chapter we have seen how man has been enabled to make the ray of light obedient to his will as a taker of likenesses. But recently the light-rays have been still further conquered by aid of selenium, and made to carry the human voice from one person to another some distance apart, so that we can at present, certainly to a very limited extent, talk by light-rays similarly to our power of doing so by electrical pulsation or vibration in the manner already described at p. 606, *ante*.

Wonderful as this may seem, a still greater matter of astonishment is that we can photograph by light and electricity, not in the manner described in the preceding pages, but at a great distance between the operator and observer. To explain this we quote the following, being the substance of a paper read before the British Association at its meeting in 1881:—

"Mr. Shelford Bidwell read a paper, in which a means of transmitting pictures of natural objects along a telegraph wire was described. This invention is an application of the well-known effect of the action of light upon selenium in altering its electrical resistance.

"The transmitting instrument consists of an oblong box about four inches by two inches by two inches, containing a selenium cell, through which the current from a voltaic battery passes. All light is excluded from the box except so much as can pass through a small pinhole drilled in one of its sides opposite to the selenium cell. The picture to be transmitted is focussed by a photographic lens upon this side of the box; and by a simple mechanical arrangement the box is caused to move in such a manner that the pinhole describes a series of very close parallel lines across the picture, thus covering successively every point of it. At the receiving station the movements of the pinhole across the focussed picture are exactly imitated by the motion of a platinum point across a sheet of paper which has been prepared by soaking it in a solution of iodide of potassium.

"The platinum point is connected with a local battery, and the current passing through the point causes it to trace a series of brown lines upon the paper, the colour being due to the liberation of iodine. These lines are so near together—being only $\frac{1}{64}$ inch apart—as to present, at a short distance, the appearance of a uniformly-coloured surface. If, from any cause, this local current ceases to flow, the point will make no mark, and the paper will retain its original whiteness. The same effect will be produced if the local current be neutralised by an equal current travelling in an opposite direction. The current which travels along the line wire from the transmitting station (which may be one hundred miles away) is opposed to this local current, and the strength of the latter is so adjusted by means of resistance coils that when the pinhole is in the brightest part of the focussed picture, and the selenium cell most highly illuminated, the two currents exactly neutralise each other.

"If, under these circumstances, the point were to move across the prepared paper, it would, of course, make no mark; but when the pinhole is in a darker part of the picture, the illumination of the selenium is less intense. The strength of the current passing through it is diminished, the local current consequently predominates, and the platinum point in moving over the paper traces a line which will be lighter or darker in correspondence with the brightness of that part of the focussed picture in which for the time being the pinhole happens to be situated. It is thus evident that, by the introduction of gaps or the enfeeblement in suitable places of the close parallel lines traced by the platinum point in the receiver, an exact monochromatic counterpart might be reproduced of the picture focussed upon the box in the transmitter.

"In practice the instrument has been limited to the transmission of tolerably simple pictures in black and white, projected by a magic lantern; but with a more sensitive selenium cell and a more delicate sensitised paper there is little doubt that its efficiency could be almost indefinitely increased."

Gelatine Processes.

In the preceding pages we have devoted considerable space to a minute description of various processes that have been invented in respect to the use of collodion for producing negative and positive pictures. So universal became the employment of collodion, that it appeared as if it would never have a rival in the hands of the photographer. But, although of comparatively easy manipulation in the hands of amateurs, and the lower order of likeness-takers, its faults were too manifest to the artistic and scientific operator to allow its many faults to be left unremedied. In the ordinary process of likeness and landscape taking, by what are called wet plates, which could be prepared *ab initio,* in a few minutes, few difficulties, except of manipulation, arose. But when dry plates were needed, which were usually prepared some days before they were used, difficulties arose which even the most experienced operators could scarcely overcome, and this led eventually to the use of gelatine in place of collodion as a medium for sensitive coating of the glass plate.

It has already been noted in the preceding pages that the salts of silver become more rapidly blackened when in contact with organic matter on exposure to light. Hence, in part, the value of collodion and albumen, the use of which has already been fully related. Now gelatine is a product of animal matter, and is, chemically speaking, in many ways analogous to albumen. The most familiar forms in which gelatine is

seen are as glue, size, and that kind which is used for culinary, confectionery, and pharmaceutical purposes. The coarser kinds are produced by boiling waste skin, hoofs, bones, etc., while a familiar form of the better kind is found in the ordinary calves' feet jelly. The preparation of the fine forms of gelatine has now become a distinct branch of manufacture, and without being in any way invidious in the selection of names, we may mention that of Mr. Nelson, whose manufactory is situated at Emscote, between Leamington and Warwick. It is from the kinds of gelatine manufactured by that gentleman that British manufacturers chiefly draw their supply, and whose name, therefore, so frequently appears in works on photography in describing various kinds of gelatine dry plates.

As we proceed in describing some of the numerous processes that have been proposed for adapting gelatine to the photographer's purposes, many details essentially different from those of the collodion process have to be attended to. Of course those who are thoroughly up to collodion practice have only to study the details special to the new process. It may be both interesting and instructive to all, if we quote the following remarks on the character and uses of both collodion and gelatine, from a paper contributed by Mr. A. A. Campbell Swinton on "Amateur Photography," which appears in the *British Journal Photographic Almanac* for 1882. Mr. Swinton remarks as follows :—

"In 1851, Mr. Scott Archer gave to the world his beautiful collodion negative process. Professional photography at once revived and attained a position as a trade which it has never lost since. Amateur photography also revived to a great extent, but only again to sink to a level—if not quite, yet very nearly—as low as before. The collodion process was undoubtedly beautiful, and has produced, and still produces, many of the most lovely examples of photographic art. It was eminently suited for professional purposes, as may be seen by the immense struggle that the new gelatine process has found necessary to make in replacing it. For amateurs, however, it was not well suited. The preparation of the sensitive film was both messy and a great labour. A dark room or tent, together with a whole paraphernalia of baths and chemical solutions, had always to be at hand for the development of the image. Every operation—from the first cleaning of the bare glass plate to the final fixing of the negative—had to be performed within a few minutes of the actual taking of the picture.

"Dry collodion plates, which ameliorated in some measure these evils, did, it is true, exist; but they were, at the same time, expensive, troublesome, and uncertain, while the long exposures they required rendered them quite inadmissible for many subjects. In short, the collodion process was not in any form really adapted for amateurs, and amateurs would not adapt themselves to its requirements. Some there were who had sufficient perseverance to master the details and working of wet-plate photography, but a large proportion of those who attempted to do so either failed or found that the 'game was scarcely worth the candle.'

"During the last two or three years, however, a rival to collodion has stepped into the arena. Plates coated with an emulsion of gelatine and silver bromide—infinitely superior in point of sensitiveness to those prepared with either wet or dry collodion—are now articles of commerce, and may be bought everywhere for a few shillings per dozen. These plates are dry, are bought ready for exposure in the camera, and will keep for months (if not for years) without the slightest deterioration. Could anything be better suited for amateur photography? Nor is this all; for the advent of these dry gelatine plates has produced special cameras and sets of photographic apparatus for their use, which, complete, only weigh a few pounds. With such light apparatus, it is true, only small negatives can be obtained; but if these latter be clear and well-defined, they can afterwards be enlarged to any size. Cumbersome and fragile apparatus need, therefore, be no longer carried by the amateur photographer; and the tent, baths, or chemicals need not be dragged from place to place. The camera, lens, stand, and a supply of plates—in all weighing only a few pounds—are all that are requisite, development and all subsequent operations being put off till a convenient occasion presents itself. Even this is not necessary, as the exposed plates can be sent to a professional photographer, who, for a small charge, will develop, print, and finish the pictures.

"In this shape photography recommends itself especially to the traveller and explorer. To the former it presents a ready means of bringing back with him faithful reproductions of all that he sees, which will be ever present to remind him of his travels. To the explorer, on the other hand, nothing could be more invaluable, as it furnishes him with an infallible means of bringing back with him from different countries absolutely true reproductions of all that he has discovered."

Such are some of the advantages which the new gelatine processes afford the photographer. The substitution of a film of dried gelatine for the thin layer of wet collodion, which the photographer formerly employed as a vehicle to retain the sensitive salts of silver in a suitable condition on his glass plate, has involved considerable alterations in the mechanical appliances used in photography. For out-of-door work, or work away from home, the photographer no longer requires to carry what was practically a portable laboratory. Not having to "develop" his pictures on the spot, he need take with him neither dark tent nor chemicals. On the other hand, he must have some provision by which his store of dry plates can be placed, one after the other, in the camera, and properly "exposed," without the risk of the slightest ray of light reaching their sensitive surface, other than the light properly directed upon them by the lens. As he wishes to carry an ample supply of plates with him, and as the glass plates themselves make an appreciable burden in a long walk, it is essential that the apparatus for carrying them

should be as light as possible; hence have arisen considerable improvements in the camera and its "slides." Again, the increased sensitiveness of the gelatine films makes it possible to give exposures shorter than can be effected by the hand uncapping and recapping the lens; hence the invention of numerous "instantaneous shutters," by which exposures of a few hundredths of a second can be given, and pictures of moving objects readily secured. These are but instances of the many novel appliances which this recent progress in photographic science has originated.

We must next enter into some of the details of the gelatine process, so as to give sufficient information to enable our readers to understand it, and to commence and practice this branch of the art of photography.

In physical character, at ordinary temperatures, gelatine is soft, and, to a certain extent, elastic. It may, by drying, be made to assume a great degree of hardness. Some of the uses to which it has already been applied in photography, have been mentioned in the description of Sir H. James's method of zincography, at page 660, *ante*, and at page 661, where Paul Pretsch's process has been described. In each of these instances it will be noticed that advantage is taken of the fact that gelatine has the property of swelling when wetted with water.

Dr. Dawson remarks, in the *British Journal Photographic Almanac*, that "The preparation of gelatino-bromide dry plates is exceedingly easy—greatly more so, while being, at the same time, vastly less messy and offensively troublesome—than the manufacture of pyroxyline and collodion, with the after necessary abominations attendant on the latter. Moreover, the digestion of gelatine-emulsion can very conveniently be going on in one's sitting-room, whilst the operator may be looking after other duties which require his attention. It is true that great care is requisite—first, in measuring or weighing out the necessary chemicals; but every photographer, from the nature of his calling, should be handy at these operations. Then, the digestion goes on with but little attention if preliminary precautions be taken as to the continuous regulation of the heat applied. The washing and filtering of the sensitive compound are also very easy matters. The arrangements connected with the coating and drying-room are those which require to be most carefully carried out, so as to ensure plenty of working space, with freedom from dust, and uniformity of temperature, including a safe light whereby to conduct operations. Now such arrangements should not in the least interfere with those of the studio, or of outdoor photography. The preparation of gelatine plates can proceed quite as satisfactorily at night as by day, and thus many spare or idle hours of the photographer's time might be utilised greatly to his own satisfaction and profit."

But the question still is—What are good plates, and how to make them? On this subject we first quote some advice given by Mr. B. Wyles in the Journal just quoted:—

"Many as are the formulæ and instructions for gelatine plate-working, it remains a fact that many gentlemen of ability and intelligence have found failure the rule and success the exception in their efforts. For the sake of those who would know what they are using, and be able to practice 'self-help,' the following jottings are put together, and any one, with intelligent care, may prepare plates for their own use.

"It must be remembered that from the same ingredients may be made at will either the slowest or quickest of plates, the difference being due to—first, time; second, heat; and third, ammonia.

"A convenient cooking vessel is the common two-inch brown preserve jar that has a lid dropping into the neck. In it is placed—

"Bromide of ammonia (Johnson and Son's make) . . 260 grains.
Gelatine (Henderson's) . . 60 ,,
Water . . . . 4 ounces.

"This is set in a pan of water and placed over a ring-burner.

"Silver nitrate . . . . . . 400 grains.
Distilled water . . . . 4 ounces,

are put into a glass flask, and the flask immersed in the same outer pan of heating water.

"With an occasional shake, by the time the water is 'hot,' the ingredients in both vessels will be dissolved. How hot the whole should now be and *kept*, we will speak of by-and-by. The mixing is performed by pouring the contents of the flask into the brown jar in a thin dribble, stirring thoroughly with a glass strip or silver spoon all the time. The brown jar is replaced in the pan of hot water, and kept at as near one temperature as possible for the time desired, which time will depend on the sort of plate desired. Suppose a good 'general use' plate be required, which will give *any* amount of brilliancy, and work tolerably quick; digest at 130° for an hour and a-half. Whilst this is digesting, weigh out 240 grains of Henderson's gelatine, soak in cold water, melt, and, at the end of the time of digesting, pour into the emulsion. Set the jar at once in *cold* water until it is cooled to from 90° to 100°, when one drachm of strong liquor ammoniæ may be added, and the emulsion left to set.

"*Washing* is done by squeezing through a canvas bag on to two thicknesses of muslin tied over a wood vessel, and after soaking in two or three changes of water (say) half-an-hour, the emulsion is gathered up with a silver spoon and re-melted. At the same time, 300 grains of Nelson's No. 1 gelatine, previously soaked, is melted and added. An ounce or two of methylated spirit appears to make it spread easier. The whole bulk is made up to twenty-five ounces, when it is run through wash-leather (well cleaned with soda), and is ready for—

"*Spreading.*—This is simply done by running the emulsion through a *pure* rubber tube, with a clip at the end held in the left hand, the emulsion being guided over the plate with a glass rod held in the right. The tube is attached to a glass holder surrounded by a metal jacket containing hot water, which is simply hung up over the glass slab.

"*Drying* is an important part of the programme, and discouragement is likely to be met with if it cannot have a fair chance. A drying-box will do for a few, but the writer soon found it desirable to partition off the end of a large dark room, making a sort of inner dark room of it, with a self-acting door. Cold air constantly comes in through an opening from the outer air, and, passing through stove-piping into a sheet-iron stove containing a ring burner (the products of combustion never entering the room), passes out at openings made at three different heights into a chimney. It is wonderful what a draught there will be in a small room arranged in this manner, even without the help of the stove. Plates may be dried spontaneously, if preferred, and it proves a very useful adjunct for negative drying in damp weather.

"If care be taken not to submit the gelatine to more heat than is necessary, either in cooling or drying, little fear need be entertained of frilling or other defects; but to make sure one-twentieth to one-tenth of a grain of chrome alum per ounce may be added. Adding more than one-tenth, I find, introduces imperviousness of the film and *apparent* slowness.

"Bromide of potassium may be used in the proportion of four to five of silver, if preferred, to the ammonium salt. I have used both quite successfully, but have settled down now to the formula just given. For the proportions of the salts I am indebted to my old friend, Dr. John Nicol, and, having gradually worked out a system of producing any sort of plates from it by variation of treatment, I can recommend others to apply a part of their winter leisure to the same course."

Another writer (Mr. Dixon) makes the following remarks in the same "Journal-Almanac" on "The Advantage of Home-made Dry-plates," and as they are very practical they must necessarily be of service to our readers. His remarks are as follows:—

"Scarcely any photo' aphic topic has created more interest for some time past than gelatine dry plates. Before Mr. C. Bennett revealed to the profession his valuable discovery how to make rapid dry plates no one would have prophesied the change that has taken place from the use of wet to dry plates; and ere this few will have failed to have found the benefit both as a new power for accomplishing certain species of work that could not possibly have been attained with the wet, as well as a pecuniary benefit. Still, I believe the bulk of photographers might reap more benefit if they would make their own plates. By so doing we should better understand the special class of dry plate that would suit our requirements; we should also be able to keep in stock any size to suit our convenience, to say nothing of the saving that would be effected to that class who could do with a little more work. There is often some period of the year when one can spare time to devote to this purpose.

"It is an easy matter for me to make a gross of quarter-sized plates in a day, and follow the general studio work as well. I can superintend the cooking and other operations during the day and coat the plates in the evening. I should estimate the cost of my plates to be not more that sixpence per dozen. Now the average cost in the market will be near two shillings per dozen; thus I have made eighteen shillings, if the operation has been successfully performed, for my day's labour. Ventilation must have the greatest attention. I have had more failures on that account than any other, not only during the drying of the plates but during the time of cooking, etc. The drying-box or room should be warmed up to 60 deg. Fahr.

"My method of preparing these plates has nothing new to recommend it, but is merely what is published from time to time in the journals. If my remarks are not already too long I will give the formulæ I use, which enable me to make dry plates equal to any I have hitherto bought in the market:—

"Nelson's gelatine . . .	50 grains.
Bromide of ammonium .	130 ,,
Water	5 ounces.
Silver	200 grains.
Water	4 ounces.

Dissolve both, and then mix the latter with the former drop by drop, stirring all the time. The bottle or vessel containing the mixed bromide solution is placed in a tin vessel with water to come up above the level of the solution, and is kept just under boiling point for about two hours for an ordinary rapid plate; for an extra rapid one say three to four hours. Cool down to 110 deg., then add 150 grains of Coignet's gelatine, and when melted pour out into a dish to set in a cool place; then wash by any of the methods most convenient, and add 100 grains more of Nelson's gelatine. Melt the emulsion, and add ten drachms of alcohol; filter and coat the plates.

"Be careful that the emulsion be not heated to more than 100 deg. Fahr., after adding the last gelatine, or in all probability it will lose its settling properties considerably."

Into any further details of the preparation of the gelatine plate we cannot here enter, but refer our readers to the journals we have already quoted, in which the subject is discussed exhaustively.

In regard to exposure in the camera, we must leave our readers to follow the general instructions already given in regard to the collodion process, and to the results which experience alone can give, for it will be seen that, as already pointed out, so many physical circumstances interfere with any empirical instructions that might have been offered as to render such all but valueless.

In regard to developing gelatine plates, pyrogallic acid usually plays an important part, but no set formulæ for developers can possibly be suitable for all makes of plates. The amateur photographer will do well, therefore, if he buy the gelatine plates already prepared, to ask of the maker what kind of developer is best suited for his purpose, and, in the event of making the plates himself, he might similarly place the

formulæ he has used before any photographic chemical dealer, and thus get suitable directions and advice on the subject. We have already stated that many professional photographers in our large towns will undertake, at a comparatively trifling cost, the duty of developing and fixing gelatine negatives for amateurs, and also give enlargements of small plates. These will keep for a long time after exposure in the camera before they need development and fixing.

Our limited space will not allow us to go further into the minutiæ of the gelatine process. For those who require ample information on the subject, this can be obtained by consulting the *Year-Book of Photography*, and the *British Journal Photographic Almanac* for 1882, where a large number of formulæ, etc., will be found.

Ferrotype Process.

The Ferrotype process, from ease of manipulation and extraordinary cheapness, has recently come into much popular favour. In it thin sheets of iron are used in place of glass. Generally speaking, the course of operation is similar to that pursued in the ordinary collodion process. A writer in the *Year-Book of Photography* gives the following advice on the process generally:—

"The ferrotype plates must be cut to fit easily into the carriers, and care taken not to handle them with dirty fingers, as grease marks are difficult to detect, and are the cause of many failures. The plates are cleaned by rubbing them with a tuft of cotton-wool moistened with alcohol, and polished with a piece of old soft flannel. Any of the commercial samples of negative collodion are suitable for ferrotypes. Mr. Heighway remarks, however, that a collodion containing the potassium salts should not be used, as the films are rendered thereby too transparent, and he recommends the following formula:—

"Ammonium iodide . . .	35 grains.
Cadmium iodide . . .	25 ,,
Cadmium bromide . . .	20 ,,
Pyroxyline	60 to 80 ,,
Alcohol	5 ounces.
Ether	5 ,,

"The silver bath may be prepared with either distilled or tap water, and should be about forty grains to the ounce in strength. A small quantity of potassium iodide is added, and dilute nitric acid drop by drop, until the solution is faintly acid. When tap-water is used, the solution is rendered faintly alkaline, and exposed to daylight in a clear bottle for a few hours. The dark precipitate is filtered out, and the solution, after acidifying, is ready for use. The bath should be always kept carefully covered up, and filtered each night after the day's work, the necessary additions to its strength being made from time to time from a stock 60-grain solution.

"When small plates are employed, they may be held in the fingers while being coated. The plate is waved to and fro till the collodion is set, and it is then lowered steadily into the bath, care being taken that the action is not arrested, otherwise wave-marks will make their appearance on the plate. The time of sensitising varies according to circumstances; but two or three minutes in summer time, and a little more in winter, will usually be found sufficient. After careful draining, the plate is placed in the carrier, and a piece of glass fitted into the back to support it during exposure.

"It is advisable in all cases, where possible, to make use of a camera with repeating back, as by this means a large saving of time is effected, and several pictures can be taken on one plate. The cameras and lenses should be always kept carefully covered over with a cloth when out of use, and the inside of the apparatus wiped out at frequent intervals with a damp cloth. The development is carried out with ferrous sulphate, the proportions recommended being—

"Ferrous sulphate	1 ounce.
Water	16 ,,
Acetic acid	1 ,,

The plate is supported on a piece of glass during development. As in all other branches of photography, a perfect picture will result only from a correct exposure; an over-exposed positive being flat and wanting in contrast, while under-exposure yields results wanting in half-tones. A correctly-exposed picture will commence to make its appearance as soon as the developer is poured on the plate, and, when sufficient intensity is obtained, the plate should be flooded under the tap, and fixed either in a solution of potassium cyanide or hyposulphite of soda. It is then washed thoroughly, and dried over a spirit-lamp or before the fire.

"The plate is varnished with any of the samples specially prepared for the purpose, a kind recommended by Mr. Heighway consisting of fine bleached shellac dissolved in alcohol. When varnished, the pictures are trimmed and mounted either in envelopes, lockets, or on cards, and, if necessary, can be coloured with dry powdered colours." Instructions for this have already been given at page 662, *ante*.

CHAPTER XXI.

MISCELLANEOUS ARTS AND MANUFACTURES.

IN the preceding portion of this work, the most important manufactures carried on in this and other civilised countries have been described and illustrated. Their importance cannot be exaggerated, whether in regard to the necessities of life, the amount of capital invested in them, and especially on account of the enormous number of persons employed in them. There are many branches of industry we have yet omitted to mention, not because they are of little importance in regard to the wants of civilised life, but rather that their importance is limited to specific purposes than to those of a general character.

The subjects, *en masse*, present a somewhat heterogeneous character, but by grouping them this difficulty will disappear. Many of them have already, in some measure, been dealt with in the earlier portions of this work, in connection with cognate subjects, to which in fact they may be considered as supplementary, while others possess a distinctive character, which places them in but little relationship with other arts and manufactures.

BOOKS, WRITING, PRINTING, ENGRAVING, ETC.

Next to the power of speech for communicating our ideas, etc., to others, the art of writing is one of the greatest importance. *Litera scripta manet.* Our ideas once committed to writing cease to remain our own, but are the common property of mankind. The ancient history of the art, in its broadest sense, includes the hieroglyphic figures, so well known as inscribed on ancient monuments, an example which is familiar to all in the case of Cleopatra's needle.

We now turn to the modern history of books, etc. Into a description of the manufacture of paper we need not here enter, as it has been fully dealt with at pp. 3 and 4 of the present volume. At pp. 6 and 7, *ante*, will be found tables giving a full description of all the materials now employed in making paper, so far as produced directly by growth. But the chief materials are mostly old linen and cotton rags if the best kinds of paper are being made. We next turn to—

Pens and Ink.—Formerly, that is within say the present century, at its earlier decades, the quills of birds—hence "quill pens"—were the sole method of writing on paper, a method now almost entirely superseded by the use of steel pens.

When the barrels of the quills of birds are properly prepared for use, the broad barbs on the inner edge are usually stripped off to make the quills lie closer together; and they are then made up into bundles, commonly of twenty-five each, and bound up. Sometimes quills are prepared for pens by dipping the barrel in water, heating it at a charcoal fire, scraping or pressing it flat, and allowing it to swell out again to the cylindrical form: by this means an increased elasticity is given to the pen. The quill-dresser receives the quills in large promiscuous bundles, just as they are plucked from the birds, and he sorts them into various groups according to their qualities. Those of the largest size and longest barrel are called "primes," and are set aside for making the best and dearest pens; the next in point of size and quality are called "seconds;" while the worst are designated "pinions."

The quills being thus prepared, come into the hands of the "pen-maker." This is really an art, for a good quill may be placed in the hands of some who are utterly incapable of converting it into a pen. The Editor of this work early acquired the art through perseverance, but more especially that in supplying quill pens for about 100 boys at school, he thus contrived to get two half-holidays weekly, and thus escaped the classes on algebra and classics. Some persons regularly employed on quill-pen-making will make nearly 1,000 per day. Several inventions have been made of small machines to make quill pens, but we have never used a pen so made that was worth writing with.

As already mentioned, the steel pen has practically entirely superseded the quill. The mode in which steel pens are made differs in different establishments, but the following will give a general idea of the process. The steel is rolled into very thin plates, and cut into strips; these strips are annealed, and rolled to the thickness of about one-hundredth of an inch. A stamping-press cuts out pieces of the proper size for pens, with the fibre of the steel running lengthwise of each piece; and a hardened steel punch and matrix, attached to a powerful fly-press, cut the pieces to the outline shape of pens. The shaped pieces are put into an iron box containing tallow, heated in a furnace, emptied out upon hot ashes, and cooled gradually. A chisel with an exquisitely fine edge is brought down upon each piece with such exactness as to make a slit about two-thirds through the thickness of the steel. The other slits are made, the maker's name stamped, and the "dishing," or hollow form, given to the pen by stamping. After this the pens are heated to redness, and quenched in cold oil, by which

PORTRAIT AND MEMORIALS OF WILLIAM CAXTON,
THE FIRST ENGLISH PRINTER.

they become tempered. They are then shaken up together, thousands in number, in a cylinder which has a curious agitating movement given to it; so that by their mutual friction they rub each other smooth and bright, and remove the rawness of the edges. They are then tempered and coloured according to the taste of the manufacturer. This will give some idea of the kind of processes whereby the sheets of steel are converted into pens. The "holders" for the steel pens are made of various materials—wood, ivory, gold, silver; the quill of the porcupine is also used for the same purpose.

Pencils vary according to the material employed; that in most general use is "black-lead." This name is entirely a misnomer, as not a particle of lead enters into their composition. The "black-lead" is what is commonly known as "plumbago." This mineral, in its best condition for pencil making, is found in Cumberland, so far as England is concerned. At Borrowdale, near Keswick, a mine of black-lead was accidentally discovered in the reign of Queen Elizabeth, and has ever since yielded a large supply of the material. At the present time large quantities are imported from Ceylon and other places abroad. The dust forms the well-known domestic black-lead used to polish stoves, and as a lubricator and polisher of machinery; for the latter purpose it is especially suitable, from its greasy or unctuous touch, although of course not containing a particle of grease or oil. In making pencils, the cedar, forming the outside, is cut up into planks, slabs, and rods, and the grooves are made to receive the black-lead, which has already been cut up into slender rods. The two halves of the pencil are then glued together. The various degrees of hardness depend on the quality of the black-lead. At the present time a kind of carbon pencil is made, which in many cases may be substituted for ink in writing. Coloured pencils are made in a similar manner, with the exception that coloured earths replace the black-lead. The same remark applies to "crayons" used for drawing purposes, which, however, are destitute of the external cedar case.

Ink.—On this subject, perhaps, the less said the better. From the school-boy to the editor, loud and continuous complaints are made about the ink. But this is not to be wondered at considering how ink is treated. It is generally poured into an ink-pot which, at least during the day-time, is exposed to dust and dirt of all kinds. Containing necessarily water, the latter evaporates, and, from both causes, it rapidly becomes thick, clogs the pen, and irritates the temper of the writer. All writing inks are merely a kind of dye, whose material is held in solution. Remarks on this subject will be found in the chapter on Dyeing, etc., in this volume. Most kinds of black ink have iron as their base; this, with galls, forms a black mixture. But the actual making of black ink involves a variety of processes that vary with the ideas of the maker, whose great object is to produce an ink that gives a good and lasting black, and that flows readily from the pen. Red writing ink used to be made from cochineal or logwood, combined with other chemical agents. At the present time, the various aniline dyes, described in the chapter on Dyeing, etc., in this volume, are largely used for making every variety of coloured inks except black.

Printing ink contains oil; whereas writing ink does not. The former is made principally of oil and carbon, and has the property of adhering with much firmness to the surface of moistened paper—indeed, the adhesion is so strong that it would require chemical processes of great nicety to separate one from the other. Oil is boiled in a cauldron until it loses a great deal of its greasy quality; and the ink-maker provides two kinds of this "varnish" (as the boiled oil is called) having different degrees of thickness or consistence, since the state of the weather and the kind of type influence the thickness of the ink required in printing. For making black printing ink, the varnish is mixed with lampblack; for red ink, with vermilion. The varnish and the colouring material are ground up well together; and one or other of some other materials is generally added, including turpentine, resin, soap, and treacle. The ink used for printing from copper or steel plates, or from lithographs, is much the same in its general characters as that used for printing on the press, but it is less viscid, and consequently more tractable in use.

A variety of writing materials must be here simply passed over by naming them—such as wafers, sealing-wax, envelopes, etc., etc. We therefore next pass to the important subject of

Printing.

The discovery of the art of printing is to a large extent hidden in respect to its early history. Much has been written on the subject, but little is actually known.

To William Caxton is due the merit of having printed the first book in England. Caxton is supposed to have been born about the year 1412.

Caxton was an industrious translator as well as printer, for he gave himself the trouble of translating into English many of the books which he afterwards printed. He spared no pains in obtaining correct copies of the works which he printed; and this was in many cases a difficult matter, for as all the books before that time were in manuscript, the process of copying with the pen was very likely to lead to variations in the subject-matter of the book, arising out of the ignorance or the carelessness of the transcribers.

Caxton appears to have employed five distinct "founts," or sets of type. The first of these, with which his earlier works were printed, was the sort called "Secretary," and of this he had two founts; afterwards he had three founts of "Great Primer;" and then others of "Double Pica" and "Long Primer,"—these being the names employed by printers to designate the kind of type employed by them.

A number of other printers soon followed Caxton's example, and printed books multiplied

very rapidly. Each printer, having a sort of pride in the excellence of his own workmanship, adopted a "mark," or symbol, which generally comprised a small but rude woodcut, together with certain initials or inscriptions.

Fig. 346.—Early Printers' Marks: Wynkyn de Worde.

That represented in Fig. 346 belonged to Wynkyn de Worde, who was a friend and assistant of Caxton.

Printing-types are made of a mixture or alloy of lead and antimony. The early printers were a good deal perplexed to determine the proper materials for types, since the metal ought to melt easily, and yet be hard when cold. The above two metals are now found to be fitted for the purpose: there are from three to five parts of lead to one of antimony, according to the size of the types, the smallest requiring the most antimony in order to make them harder. The type-founders have an immense variety of moulds for casting type—Roman, Italics, old English, Greek, capitals, and small letters—very minute "Diamond" and very large "Double Pica"—numerals and stops, etc., in order to meet the requirements of the several kinds of printing. The largest type commonly employed in printing a book is that called "Double Pica," of which 41½ lines go to a foot; while the smallest is "Diamond," with 205 lines to a foot.

When the types are cast, they are cleansed from the superfluous metal, and rubbed on the two opposite sides to make them flat and smooth. They are next set up on end, face downwards, and a plane is run over them, to ensure all the types being exactly of the same length—a point essential to the proper arrangement of them for printing. The types are then formed into "founts" or sets, and delivered to the compositor.

The compositor, whose labours consist in setting up the several letters in the proper order for printing, is provided with an apparatus called a "frame." This frame is a sort of desk, in front of which the compositor stands while at work. The frame contains two pairs of "cases," one pair for Roman letters, and one for Italics. Each case contains a great number of divisions or compartments for the several letters of the alphabet. The upper case of each pair contains compartments for the capital letters, the numerals, the accented vowels, and the marks of reference for notes; while the lower case of each pair contains the small letters, the stops, and the spaces which are to be placed between the words. The compartments are very numerous, and are planned, with respect both to their sizes and their relative positions in the case, with singular ingenuity.

The compositor holds in his left hand a small piece of apparatus called a "composing-stick" (Fig. 347). This is a metal frame with one side movable, so that it may be adjusted to the required width of the column or page about to be printed. It will contain about ten or twelve lines of average type. The manuscript from

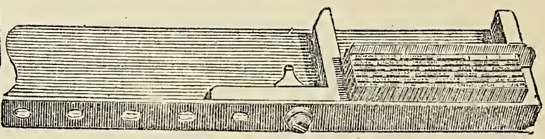


Fig. 347.—Printer's Composing-stick.

which the printing is to be copied being placed open before the compositor, he reads a line or two of it; and, retaining the words in his memory, proceeds to pick up the letters one by one which will form the words, adjusting them in their proper order in the composing-stick, and placing the spaces which are to divide the words one from another. The rapidity and accuracy with which this is done are quite remarkable, and evince the tact which is obtainable by long practice. He places letter after letter, and word after word, until he has reached the end of his composing-stick; he then begins a new line, and proceeds on the same way until the stick is filled. He then grasps the whole of the letters in his fingers so dextrously as not to allow one to fall, and transfers them to a flat plate called a "galley."

The work of the compositor proceeds until he has as many lines set up as will fill a sheet; and he arranges his lines in the proper way one beneath another. Sometimes the pages of the book are made up as far as the type will go, before the "proof" is sent to the author for his revision; while on other occasions the type is put together in long slips or columns, to be afterwards adjusted into pages when the revision has been effected. Before being sent to the author, however, the proof is "read" carefully at the printing-office; that is, one person reads the author's manuscript while another reads the printed sheet, to see that the two agree, and to make the necessary corrections where they do not.

When the reader has performed his task the compositor corrects his work; another copy is printed, and this copy, designated the "proof," is sent to the author, who adds or curtails or alters just as he may think the necessity of the case requires. Some proof-sheets are sent back by the author scarcely altered at all, while others

are so completely cut up that the compositor has to do nearly all his work over again.

Preparing for Press: Stereotyping.—When the corrections are finally completed, the proper book-form is given to the type (if it had not been done before). The compositor is provided with a number of pieces of apparatus, by which he is enabled to wedge the types together so closely as to bear the action of the printing-press or machine. In the first instance, after he has transferred as much type from the "composing-stick" to the "galley" as will fill one page, the compositor binds this group round with a string. Then, when he has as many of these groups as will fill one side of a sheet of paper, he arranges them in proper order on a bench called the "imposing-stone;" he surrounds each page-full of type with pieces of wood called "furniture," in order to keep them at the proper distance apart. If there are sixteen pages in a sheet, as for *octavo*, there are eight on a side, and therefore eight are arranged together in this way; so that the number of pages thus collected depends on the size in which the book is printed. The whole of the pages, with the "furniture" between them, are then wedged tightly together in a stout iron frame called a "chase;" and this frame, with its contents fixed immovably in it, constitutes a "form." Another "form" is built up in a similar way, containing the pages which are to print the other side of the sheet; so that the sheet of paper, after being printed by one of these "forms," may undergo a second printing by the other.

In common type printing, the form is carefully examined to see that all the letters are on one general level, and that the inking would not be stronger at one part than another; and after this the printing proceeds. But in modern times a great feature has been introduced, under the name of "*stereotyping,*" by which the printing is not effected from the types themselves, but from a cast from those types.

The process of stereotyping requires that a mould should be taken from each form of types, and that a cast should be made from the mould sufficiently true and clear to print from. Hence there is a double process of casting for each page contained in a book—a striking proof of the large amount of trouble willingly incurred to gain the object in view. The page of type is wedged up securely in an iron case, and the surface carefully examined to see that no dirt or other imperfection interferes with the correctness of the surface. The page, thus secured, is placed in a case called the "moulding-frame."

The cast is made of a mixed metal of antimony and lead, like printing types themselves; and the metal is melted in a copper containing about half a ton, and then poured into the mould.

This cast is now an exact representative of the original page. The mould was a reverse, giving in intaglio or cavity all the parts which were raised or in relief in the page, and *vice versâ;* but the metal cast reverses this again, so as to come back to the original form. The stereotype plate, before being printed from, undergoes a very careful examination. If any slight corrections or additions are required, parts of the plates are cut or filed away, and other parts put in; if any of the letters have become filled up by the material or the metal, they are opened and properly shaped by small sharp tools; and if any of the fine lines of the woodcuts have become disfigured, they likewise are restored to the proper state.

Printing by the Press.—The preceding details have arrived at the point where the printer, properly so called, or the "pressman," commences his operations. The inking of the form of types, and the pressure of this form on a sheet of damp paper, afford the two sections of the process; and both of these have in modern times been brought within the power of machinery.

From the earliest days of printing some kind of press has been employed to transfer the ink to the paper more readily and evenly than it could be done by hand. The kind of press first employed was nothing more than a common screw-press, such as a cheese-press or a napkin-press; together with some arrangement for bringing the form of type under the action of the press after it had been inked. This must necessarily have been a slow and tedious process; and as the screw must have come down upon the types with a sudden jerk, on account of there being no yielding or elastic support beneath, the pressure must have been so great as to endanger the letters.

The "Stanhope press" is a much more efficient form of apparatus. This is represented in Fig. 348. The object of the improvement was to render the printer able to produce a finer kind of work; for the rate of working remained pretty much the same as before—two hundred and fifty impressions on one side of the sheet in an hour. Numerous forms of the hand press have been invented, but printing by steam, to be presently described, has made nearly all of little

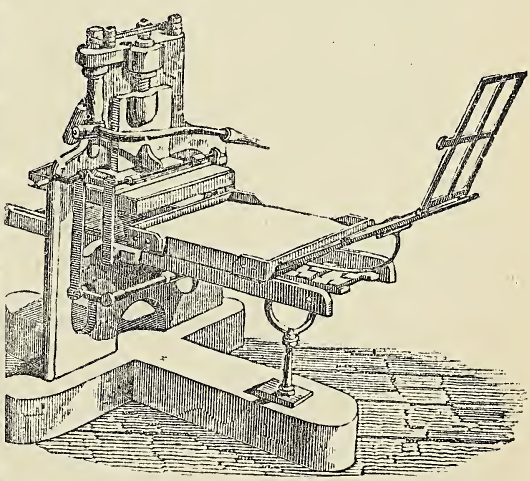


Fig. 348.—Stanhope Press.

use except by small printing firms, and as a means of producing "proofs" in large printing establishments.

Printing by the press, then, involves the following features:—The ink is spread out on a bed or cushion; and being thence taken up either by the inking-balls or the inking-rollers, is applied to the surface of the type. The form of types is so placed as to be inked conveniently; and the sheet of paper being adjusted in its place, is brought down upon the form of types. Pressure, either by a screw or by levers, then causes the impress of the inked types upon the paper. This leads to the printing of one side only; and to print the other side another form of types is used, and the paper is applied to it on the reverse side to that formerly applied.

The steam printing-machine consists of a great number of cylinders, round the whole of which the sheet of paper becomes coiled in the process of printing. The machine can print both sides of a sheet of paper at once; or, rather, the sheet does not leave the machine till both sides are printed. There are two "forms" of type on the bed of the machine at one time; one, to print one side of the sheet, near one end of the machine; and the other, to print the remaining side, near the opposite end. These forms of type have been prepared very carefully, and adjusted to the bed or flat portion of the machine, which is strictly horizontal. Some of the cylinders are so adjusted as to work over the surfaces of these forms of type; while others are intended to aid the sheet of paper in passing from one "form" to another.

Such is a general outline of the method of steam-printing machinery. We cannot here attempt to describe the various forms of machines that have been invented. Of course, the chief improvements have been made with the object of facilitating the production of daily newspapers, both in London and the leading provincial towns. We may here observe that the daily circulation of one of the leading London papers was certified by an eminent firm of auditors to be 210,000 per diem.

Books, etc.—Books essentially differ from newspapers in many respects. The latter are entirely ephemeral, and perhaps, within twenty-four hours of its publication, the most influential "daily" may find itself confined to the base use of wrapping up soap, candles, etc., or for lighting the fires of the household. In the case of paper used for books, it undergoes the process of wetting or damping. The wetted sheets are consigned to the hands of the "laying-on boy," if for machine-printing; or the "pressman," if for common printing. The printing is effected while the sheet is still damp, and in this damp state it is removed from the printing-room. In large establishments there are steam-heated rooms for drying, having a number of cross-bars and poles ranged in parallel lines. A man or boy, called the "hanger-up," suspends the damp printed sheets of paper on these cross-bars. The whole of the sheets, thus collected, are transferred to the poles or bars in the drying-room, where they become speedily dried sufficiently for binding.

Most modern periodical works undergo a little arranging and pressing at the printing-office, before they go to be stitched or bound. This arranging consists of "gathering" and "collating." On a long table are ranged heaps of printed sheets, each heap consisting of a great number of copies of the same sheet; and the heaps being equal in number to the sheets in the intended book, a boy, called the "gatherer," walks from end to end of the room, in front of the table, taking one sheet from each heap, and forming a group; so that by the time he has reached the end of the range he has collected exactly enough sheets to form one copy of the book. All the other groups he collects or "gathers" in a similar way. Then comes the "collater," who examines every sheet of every group to see that the proper order is maintained; this he does with astonishing rapidity; his examination being aided by certain letters or figures called "signatures," of which one is always put at the right-hand bottom corner of the first page of every sheet.

When the collater has examined each group, to see that it contains the proper quantity and the proper sheets for one volume, the group is folded into a thicker heap, and placed in a hydraulic press, where several such groups are made mutually to press each other. Numerous forms of hydraulic, the Boomer and other presses, have been described in the first volume of this work. This hydraulic press, like others which have engaged our notice, contains apparatus for driving up the bed or stand on which the sheets are placed. There are two pumps, worked by handles in the usual manner, and dipping at their lower extremities in the cistern of water; the water is pumped through a pipe to a reservoir, where it exerts an upward pressure, which forces the piston against the bed on which the sheets are placed. When it is desired to remove this pressure in order to take away the sheets, a cock is turned, by which the water is allowed to flow back from the reservoir to the cistern. For the better kind of books, where it is desired to give a smoothness and glossiness to the paper, glazed millboards are inserted among the sheets before the latter are subjected to the press.

Bookbinding.—The train of processes whereby the printed sheets are brought together in the form of a compact and convenient book, is not less interesting in some respects than the printing processes, though, of course, far less important.

All the sheets must be in some way sewn together before the covers or backs can be applied; or, if not sewn, some other mode of fastening must be adopted. Until the recent introduction of the mode of "india-rubber binding," all books had the sheets fastened together by sewing; and, indeed, the change has not yet reached any considerable degree, for the number of sheets fastened by sewing is, beyond all comparison, larger than those cemented by india-rubber solution.

The sewing is effected by means of small frames, or presses; and females are, in most

cases, employed at this work. When the printed and collated sheets are brought to the bookbinder from the printer, they are slightly folded for the convenience of transport, but not in the form necessary for a book. The "folder" has, therefore, to be employed before the "sewer." The sheets are taken from the piles, or groups, one by one, and each one is folded into four, eight, sixteen, or more leaves, according to the size of the work: this folding is done with great rapidity, the sheet being doubled and doubled again and again, and the creases flattened and made regular by the application of an ivory or bone folding-knife, with a degree of quickness which the eye can hardly follow.

The process of sewing is conducted so rapidly, that two or three thousand sheets can be stitched in a day by one workwoman. Sometimes the sheets are sewn to strips of vellum or leather; but in most cases common hempen string is employed; and four or five is about an average number for middle-sized books. When the sewing is completed, the upper cross-bar of the press is lowered by means of screws at the vertical posts, or else the strings are at once cut. The strings are sometimes intended to form small projections at the back edge of the book when bound, and in such cases they are left in the position which they naturally assume from the sewing; but in other cases it is desired that the back edge of the book should be quite smooth and level; and to effect this a few saw-marks are previously made to receive the strings. The sheets, too, before being sewed, are generally pressed heavily to make the leaves lie close and compact together.

When a book has been sewed, preparations are made for attaching the cover to it. This is done in rather a different way, according as the book is to be put into "boards," or "bound." The strings are cut till a little remains at each end, and these ends are scraped or thinned, to render them as little visible as possible. The back edges of the book are glued, to render their adhesion yet stronger than by sewing merely; and before the glue is quite dry, the book has the roundness of edge imparted, by a process of hammering managed in rather a peculiar way: the book dries permanently in the form given to it by this hammering. About this point of the operations, too, the leaves are so pressed as to form two recesses or grooves for holding the stiff covers of the book. The boards or covers here spoken of consist of "millboard" formed of many layers or sheets of brown paper glued or pasted together, and rolled through a mill to make them smooth, hard, and firm. The sheets of millboard, made for the use of the bookbinder, are of various sizes, according to the sort of books for which they are intended to be used. They are cut up by means of a machine. A piece of board is provided, the exact size of the cover wanted; from this as a pattern, the millboard is cut up into pieces; the cutting instrument being a blade working in a hinge, something in the same way as in a chaff-cutting machine, or a tobacco-shredding engine.

The pieces of millboard are attached to the book by means of the ends of the strings, in the case of a "bound" book, but by pasting with intermediate pieces of paper in the instance of a "boarded" book. In the former case holes are made near one end of the millboard cover; and the ends of the strings being passed through these holes, they are pasted down as flat as possible on the inner side of the cover, by which the latter becomes fastened to the book. After other minor processes, tending to give a neat and compact appearance to the boards, the book receives its covering, which is entirely of leather in a "whole-bound" book, and a combination of leather with either paper or cloth in a "half-bound" book. The leather employed is "Morocco," "Russia," "calf," "sheep," and a few other kinds, in most cases prepared by the leather-dresser to the state required by the binder. The skin of leather is cut to the required size, laid down on a smooth table with the face downwards, pasted at the back, and applied to the book, where by a very careful manipulation it is made to adhere closely to every part of the surface. Those books which have not "hollow backs" bend at the back edge whenever the book is opened; but most well-bound books are so treated, that, by the intervention of slips of pasted paper, the leather at the back edge is enabled to maintain its convex position whether the book be opened or closed.

Illustrations of Books, Engraving, etc.—Half a century ago, it was difficult to meet with a work illustrated by wood-engraving, while at the present time it is almost as difficult to find a work that does not possess them. We well remember perusing the first numbers of the "Penny Magazine" on the evening of its issue, and the delight that it caused among young persons through the interest occasioned by the woodcuts.

The method of producing wood engravings is as follows:—A drawing is first made by the artist or author of a work by pencil, on paper. This is placed in the hands of the wood-engraver, who copies the drawing on to a proper sized piece of boxwood, which has first been covered with a little chalk to make the outlines more visible. In some cases, as for example the scientific illustrations of this work, this drawing on wood is submitted to the author to see how far his ideas have been carried out. Supposing the drawing to be correct, the engraver then, by means of a sharp steel tool, cuts lines in the wood wherever any shading has to appear, leaving those parts that are light in the drawing untouched. Printers' ink is then applied to the surface and fills up the hollows. When such a cut is put into the press with paper the latter receives an exact copy of the drawing as first given to the engraver, and any number of impressions may be printed therefrom.

But, at the present day, the woodcut itself is rarely used. By means of electrotyping, copper copies are produced in a manner already fully explained in the article on Electro-metallurgy in the present volume. The woodcut itself is thus kept intact, and may be used as the basis of any amount of "electros" that may be required.

The cut thus obtained is fixed in the page of type, and subsequently printed off with it in the press in the manner already described.

Copper and Steel Plates.—For higher class of illustration, copying of large works of painters, etc., engraved copper and steel plates are employed. The use of copper plates for this purpose long preceded that of steel; the latter being comparatively a modern invention. In the preparation of copper plates for the engraver, the copper, after being cut to the required size from a sheet of the best quality, is scraped all over with a steel instrument; it is then well hammered, to render it more dense and even; it is next ground with a piece of hard bluestone wetted with water, and is finally polished with carefully prepared charcoal, by which the surface is brought to a state so beautifully uniform, that the finest mark of the graver shall afterwards be visible on it.

Copper, in many respects, is perhaps the best material for the engraver, but its softness renders it unfitted for yielding a large number of impressions. This difficulty, however, was got over some years ago by the invention of M. Joubert. By this an engraved copper plate is covered with a thin coating of pure iron by the electrotype process. The importance of this invention has induced us to give minute details, which will be found under the head of "Joubert's process," in the article Electro-metallurgy in this volume. A method of producing copper plates engraved by light and electricity, and invented by Paul Pretsch, is fully described in the chapter on Photography. The ordinary method of engraving on copper plates is the same as that on steel.

Steel plates are engraved by two very different methods—by the *graver* or *burin*, and by *etching*. The graver is a very delicate and sharp steel tool, shaped at the point in different ways according to the kind of work to be executed; and with this tool the lines are cut which constitute an engraving. A scraper, a burnisher, a cushion, and a rubber, are among the small number of implements employed by the engraver. In the process of etching, however, there is a chemical action involved, which gives rather a different character to the art. The plate is first warmed, and is then thinly coated with a composition called the "etching-ground," formed of wax, asphaltum, gum mastic, resin, etc. This ground, when laid on and smoothed, is blackened by the smoke of wax candles, and is then in a fit state to be engraved upon. An outline of the design is made in pencil upon thin paper; and this paper being laid on the plate, and both passed through a press, the lines are transferred to the etching-ground with sufficient distinctness to be visible. Small tools, called "etching-needles," are then employed to execute the engraving, by scratching lines in the composition wherever a line is to appear in the print: laying bare the metal beneath, but not cutting it. A raised border of wax is built up round the plate, and dilute aquafortis is poured on: this speedily corrodes the copper in all the parts where it has been laid bare, while the composition prevents the corrosion from taking place elsewhere. The deep or strong lines require more corrosion than the faint lines; and this is brought about by a repetition of the process in some parts only, the other parts being shielded or protected by a composition called the "stopping-ground." In a carefully prepared etched plate, the "biting-in" and "stopping-out" are repeated several times. When all is completed, the etching-ground is removed, and the plate is in a fit state to be printed from.

There are various modes of engraving plates, known by the names of "line" engraving, "stipple" or "chalk" engraving, "mezzotint" engraving, and "aquatint" engraving, but on these we cannot dwell.

Lithography.—At the present time the uses of lithography are greatly extended. Formerly it was chiefly employed for making *fac-simile* writing for circulars, etc.; now its use for likenesses, maps, etc., is very large. In the production of colour printing for book and other illustrations, it has produced a new era, and has almost entirely replaced colouring by hand. Used for this purpose it has acquired the term of *Chromo-lithography.*

The whole theory of ordinary lithographic printing rests on these two circumstances: that certain kinds of calcareous stone are capable of imbibing both water and oil or grease; and that water and oil mutually repel each other. A peculiar kind of stone, and a peculiar kind of chalk or pencil, are requisite for the practice of this art. The stone is porous yet brittle, and generally presents either a pale yellowish drab or a grey neutral tint. At the quarries whence they are obtained, the stones are split to an average thickness of about two inches, levelled at the upper surface, and squared to convenient sizes. They are then sold to other persons, who prepare them for use, by grinding two stones together, with a little water and sand between them; this grinding brings them quite flat and level, but at the same time gives the surface a granulated texture, which is necessary for the object in view, and is made coarser or finer according to the taste or requirements of the artist. This, then, is the stone employed; and the chalk or pencil, with which the design is to be made on the stone, is made as follows: it is a mixture of tallow, virgin-wax, soap, shellac, and lamp-black; these ingredients, by a careful process of heating in a close vessel, are made to combine into a uniform substance, and this substance is cast in a mould to such a form as is convenient for use as a pencil.

Supposing, then, an artist to be provided with a stone and a pencil thus prepared, he proceeds as follows:—He draws the design very carefully on the surface of the stone with the pencil, producing thereby a series of slightly greasy marks, owing to the soap contained in the pencil. These greasy marks are soluble in water, and would, therefore, wash out; but to prevent them from so doing, the stone is washed over with a weak solution of nitrous acid, which combines chemically with the soapy chalk marks, and

renders them insoluble in water. A solution of gum is floated over the surface of the stone; and when this is dry a wetted sponge is employed to bring the stone quite clean, but without removing the chalk marks. When the printing is about to take place, the stone is slightly damped with water, and is then inked with an oily ink pretty much the same as that employed in common printing; the ink is applied by means of an elastic roller worked to and fro over the stone. The water which had just been applied to the stone had been imbibed by the stone itself; but not by the chalk lines, because their greasiness repelled it; hence, when the inking roller is worked over it, none of the ink adheres to the stone itself, because that is wet; but it *does* adhere to the chalk lines, because they, like the ink employed, have an oily or greasy character. The result of this operation, then, is to ink all the marks of the design; and from thence an impression is taken on a sheet of paper by the action of a press. The greasy marks do not become obliterated for a long time; but, after each copy is printed, the stone is again wetted, and the inking roller again worked over it; the antipathy between grease and water being, throughout, the main feature on which the operation rests.

Printing by lithography in colours is now frequently adopted. In this case two or more stones are employed: one to give the main details of the picture, and the other the more delicate tints. The design (with these omissions) is made on a grained stone with the greasy chalk, and the printing from this stone is conducted exactly in the same way as in the former instance; but the printed paper, instead of being regarded as finished, is printed a second time from another stone, on which the lighter tints have been prepared in a more delicate manner. This employment of duplicate stones is not limited to the case of diversified colours being used, but is also employed for difference of shade or depth, when the colour is uniform. A large number of illustrations of books are now effected by means of coloured wooden blocks, one block for each colour. This method is also used to produce illustrations of posting-bills, and a host of similar purposes.

Music, Musical Instruments, etc.

In the last section we have dealt with subjects specially relating to intellect; we next turn briefly to a description of various musical instruments that can afford us one of the most refined pleasures which human nature is capable of enjoying. In regard to the philosophy of music, the cause of the human voice, of musical sounds, etc., it will be needless for us here to enter, as they have all been fully dealt with in the introduction to the Telephone in a preceding chapter. In a similar way the philosophy of each kind of musical instrument has been described.

The greater number of musical instruments may conveniently be collected into seven groups; of which we may take as representatives or types, the Organ, the Clarionet, the Horn, the Pianoforte, the Harp, the Violin, and the Drum.

The Organ.—An organ—whether such as is used in a church, or the old-fashioned one, such as formerly gave a livelihood to the poor Italians who wander about the streets—derives its action from the passage of air through pipes. According to the laws which regulate the production and transmission of sound, the body of vibrating air in a tube becomes more shrill or acute in pitch in proportion as the tube is shorter: hence, by a due management of the size of a set of tubes, all the notes for several octaves may be obtained, as already explained in the chapter on the Telephone.

In a *Church Organ*, which is not "self-playing," there is complexity of other kinds. The fingers of the performer act upon keys, and his feet upon pedals, which move certain levers; and these levers, by intervening mechanism, open the valves which allow air to enter the pipes. Sometimes the organist has an assistant to work the bellows for him, while at other times he works them with his feet. In large organs both steam and water power have been applied for this purpose. The great organ which was formerly in the Panopticon, Leicester Square, London, was supplied by air by aid of a four-horse power steam-engine. Above the bellows are various little scaffoldings or frameworks to support organ-pipes, which, in a large organ, differ greatly in size, and are placed in various parts of the machine. Near the bottom are the keys, which are played upon by the fingers of the organist; and at the other end of these keys is the system of levers, the action of which opens the valves that admit air into the pipes. As, in a piece of music, *melody* determines the notes which shall be sounded in succession, and *harmony* those which shall be sounded simultaneously, there is a very large and intricate arrangement of these pipes, valves, and levers necessary to meet the requirements of the musician.

Not only are there different *sizes* of pipes to produce different elevations of pitch, but different *kinds* of pipes to produce certain qualities of sound. It is this which gives rise to the organ-maker's technical name of "stop." A "stop" is a set of pipes, all similar in the general character of the sound, but differing one from another as to pitch. Each particular stop has a name applied to it: such as the "flute stop," the "piccolo stop," the "diapason stop," etc.; and each of these kinds has a peculiar character—or as the French call it, *timbre*—belonging to it, wholly irrespective of difference of pitch. Some of the large organs have a prodigious number of "stops" or sets of keys.

There are many musical instruments of considerable importance in an orchestra, in which the tones are produced mainly by the vibration of a small piece of metal or of reed in a tube, something on the same principle as one of the many kinds of organ pipes.

The *Clarionet* is perhaps the chief of these. The *Oboe* or *Hautbois* is another specimen of this

kind. The French name is *Hautbois ;* the Italian, *Oboe ;* but both are usually alike pronounced *ho-boy.* The *Bassoon,* another valuable instrument in the orchestra, is in effect a bass oboe. There are various arrangements of musical instruments which depend a good deal on some such principle as the one here under consideration, although they do not at first sight seem to be at all similar. Such for example are the *Accordion,* the *Concertina,* and the *Harmonium.* In each of these instruments there is in the first place a kind of bellows, put in action by the two hands, except in the harmonium, in which the bellows is worked by the feet. The current of air thus excited (drawn from the external atmosphere through an opening in the instrument) is forced through a number of openings, in each of which a small steel or metal spring is placed. The rapid passage of the air sets these springs in vibration, and the vibration produces musical sounds. If the current of air were allowed to act on all the springs at one time, they would all be sounded at once ; but this is prevented by the arrangement of a system of keys governed by the fingers of the performer, in such a way that he can open any one of the apertures, and thus cause the sounding of any one spring at pleasure. The arrangement of the keys, stops, etc., of the *Harmonium* is similar to that of the organ, and the effect to a large extent is similar.

Another instrument—the musical box—consists of a barrel studded all over the surface with little pins or wires. This barrel is made to rotate by the action of a coiled spring, just as in the case of a pocket watch ; and, while rotating, the studs on its surface strike against a row of metallic springs, which are thereby set into vibration. All the springs are shaped and sized beforehand, so as to yield the proper tones ; and the studs on the barrel are arranged in definite order according to the tune which is to be played.

There is a still larger class of musical instruments in which there is no vibrating reed or spring. The air is forced into them, generally with some considerable power, and is made to set the enclosed mass of air into vibration without the necessity for any springs. These include the flute, etc. It is difficult at the present day to determine what was the exact character of many of the musical instruments alluded to by the classical writers. The name *Flute* seems to have been given to many different forms of instrument, some of which are described as being straight, and others curved, small, middle-sized, single, double, right, left, equal, unequal, etc.

The instrument known in England by the name of *Flute* has not uniformly been the same in shape. It consists, as is well known, of a long tube, somewhat larger in diameter at one end than the other, stopped up with a cork at the wide end, and open throughout the remainder of the length. The tube itself is made of box-wood, ebony, cocoa, ivory, and glass—generally one of the first three, the other two being mere curiosities of luxury. The adjustment of the metal keys (generally silver) to these tubes is a work of very great nicety, and indeed the whole of the details connected with the manufacture of a good flute call for considerable skill, as also does the playing on it. The *Flageolet,* like the flute, is a wind instrument played without a reed, but it is comparatively a poor affair, and has never maintained a position equal to that of the flute.

There are many brass instruments which differ from the flute both in the form, in the number of keys and finger-holes, and in the mode in which a current of vibrating air is excited in them ; but still they belong to the general class which we are now considering, in having no reed or tongue. All the various kinds of *Horns, Trumpets, Bugles, Trombones, Ophicleides, etc.,* are of this kind, and all have a peculiarity of tone which seems to be partly due to the mode in which the breath is impelled into them, and partly to the metal of which they are made.

Stringed Instruments, played with Keys.—The large and important system of musical instruments to which a little attention may next be directed, admits of a convenient subdivision into three groups, of which all will be alike in respect to the production of the musical sounds from strings, but differ in the mode in which the strings are made to vibrate ; one by means of *keys,* like the pianoforte ; another by means of the *fingers,* like the harp ; and the third by means of a *bow,* like the violin.

The *Pianoforte,* the most generally admired, and employed among all musical instruments at the present day, has arrived at its present state by many gradations. From the time when the pianoforte became established in this country to the present day, there has been scarcely a year which has not produced some improvement or addition to it, until at length it has come to be a most intricate piece of mechanism. There are several different kinds of pianofortes made, similar in the use of hammers to strike the strings, but differing in minor particulars. The "square" pianoforte has the strings ranged horizontally in a rectangular case, two strings to each note, and having a range of five and a-half, six, or six and a-half octaves—the lowest of which equals the greatest used in the old harpsichords. The "cottage" form has the strings ranged vertically, reaching nearly from the ground to a short distance above the level of the keys ; the case is shorter and higher than that of the "square ;" there are two strings to each note, and the compass is generally six octaves. The "cabinet" pianoforte is very lofty, having the strings ranged vertically, and elevated wholly above the level of the keys ; there are two strings to each note, and the compass is from six to six and a-half octaves. The "grand" is a very long instrument, having the strings ranged horizontally, and the keys at one end of the case ; there are *three* strings to each note, and a compass of six and a-half octaves. Lastly, the "semi-grand" pianoforte is formed on the general plan of the "grand," but with a limitation to about six octaves in the compass, and having only two strings to each note. It is impossible for us to enter into a

detailed account of the variety of pianofortes existing at the present. The only way to get over the difficulty is to suggest to the reader the perusal of that portion of the London Directory referring to the manufacture of pianofortes, and, at the same time, to suggest to him that each maker will have at least one speciality to recommend him for purchase.

Stringed Instruments, played without Keys.—Although the pianoforte is the most generally acceptable of all stringed instruments, yet the number of those which are played without the aid of keys is much larger than of those, like the pianoforte, which are played with keys. A very few details will suffice to show the general principle involved in such instruments, though the varieties of form may be numerous.

The *Harp* is, perhaps, the most important instrument of this class. In the harp of modern times the ingenious and valuable feature consists in giving to each string the power to yield two or three different tones instead of one only. The instrument embraces so many octaves within its range, that if there were as many distinct strings as there are semitones in these octaves, the harp would become almost unmanageable. But this difficulty has been overcome by the ingenuity of Erard and other makers. Yet the internal mechanism of a harp becomes very complex, and requires great mechanical skill in its adjustment.

The *Lyre* is a representative of another instrument of the class now under consideration. Like the harp, the lyre consists of strings which are sounded by being pulled or touched with the fingers; but the number of strings is always much smaller.

The *Dulcimer*, and the ancient *Psaltery*, were instruments of which examples are but rarely seen at the present day. The Lute is similarly obsolete. Somewhere between the Dulcimer and the Lute may be ranged the *Zitter*, which is like the Dulcimer in shape and arrangements of the wires, but played on after the fashion of the Lute.

Stringed Instruments, played with a Bow.—There is yet another class of stringed instruments, comprising those which are played with a *bow*, or stretched cluster of horse-hairs, such as the violin.

The modern instruments of this form are of four kinds—or, if we call the dancing-master's diminutive "kit" one, five. They may be considered as embracing the *Violin*, the *Viola*, the *Violoncello*, and the *Violone* or *Contra-Basso* or *Double-Bass*. The *Violin* is too well known to require description. The *Violoncello*, a still larger instrument, is the successor of the "bass viol" and the "viol di gamba;" being superior to both: like the viola, it has four strings of catgut, of which the two lower are covered with silver wire. The largest of this family of musical instruments, the *Violone*, or Double Bass, is employed to give strength and dignity to the collected sounds of an orchestra; and in this respect it is much valued by composers. In England, France, and Italy, this instrument has three strings only; but some of the German makers add a fourth string.

In all these instruments, one of the most notable mechanical requirements is the proper manufacture of the strings, whether of wire or of membrane. The metallic strings require the wire to be very correctly made or "drawn;" while those made of membrane and afterwards coated with silver wire, require this wire to be wound spirally by a machine made on purpose. But the membranous or "cat-gut" strings (as they are erroneously called) are the most important. These are made from an internal membrane of the sheep, and require a very careful preparation to fit them for the purposes to which they are applied.

The *Drum*, as is well known, derives its action from two pieces of parchment stretched over the open ends of a cylinder. When one of these parchment heads is struck, it vibrates, more or less rapidly, according as the tension is great or small; and this vibration, together with that of the mass of air within the drum, gives origin to the sound. The parchment is stretched to any degree at pleasure by small contrivances round the edge. The *Kettle-drum* differs from the common kind, in being a hemisphere instead of a cylinder, and having one parchment instead of two. The *Tambourine* is a cylinder, or rather a hoop, with only one parchment, and without any mass of included air.

The *Cymbals*, the *Triangle*, the *Gong*, the group of *Bells*—all are examples of the elasticity of metals, and of the sonorous qualities resulting from this elasticity, when vibrations are excited. The chief manufacturing details involved in the production of such instruments relate to the proper choice of metal, and the annealing and tempering to which it is to be subjected.

Architecture.

Like food and clothing, a dwelling is one of the primary necessities of mankind. It is required for shelter, privacy, and defence. In frigid climes man needs protection from cold and rain, and in tropical regions from the excessive heat of the sun and violent winds. He needs, too, a place where he can be secluded from strangers, rest undisturbed, and ensure security for his person and private possessions. Hence habitations must have been among the earliest acquisitions desired and provided by human beings. They were, doubtless, at first of the rudest description. A natural bower or a booth, made of branches of trees, may have originally sufficed in warm climates, while caves were resorted to, or huts were formed of stone or earth in less genial lands. Thence progress was made, in the former case, to tents, the coverings of which were formed of the skins of animals or woven cloth, and, in the latter, to edifices constructed of wood or of bricks and stone, carefully prepared, and fitted, and fixed. By degrees, as civilisation advanced, buildings became better adapted for the purposes for which they were designed; more and more symmetrical in arrangement, more costly as regards the materials employed in their construction, greater in size,

and more beautiful or grand in elevation, external aspect, and internal embellishment. In no department of human industry has the inventiveness and progressiveness of mankind been more strikingly displayed than in connection with architecture. Great advance was made in this respect by the Assyrians, Babylonians, Egyptians, and other early races, as is shown by the remains of ancient temples and other structures, while in later times, palaces, churches, and magnificent edifices, in which public and private business is carried on, illustrate alike the activity, wealth, taste, and skill of modern nations. Architecture long since reached the position of one of the fine arts, taking rank in importance with painting and sculpture. With the latter it is most intimately allied, as is seen in edifices in the decoration of which carved stone work and statuary have been made use of. Various styles of architecture have prevailed in different lands and ages. Every tyro is acquainted with the names, though he may not remember the characteristics of the five established classic orders—the Tuscan, Doric, Ionic, Corinthian, and Composite,—which are distinguished from each other by difference of proportion, as well as by the form of the column, base, capital, and entablature. These, however, are only a few of the forms or models which have been adopted. We cannot here describe the numerous styles which have been developed and followed in ancient, mediæval, and modern times, and must, therefore, content ourselves with simply naming the most distinctive and important of them. The list includes:—Assyrian, Babylonian, Byzantine, Celtic, Chinese, Egyptian, English, Etruscan, Gothic, Greek, Hindoo, Italian, Mexican, Moorish or Arabian, Norman, Pelasgian, Persipolitan, Peruvian, Renaissance, and Roman. In its widest sense the term architecture means the art and science of building or constructing. Hence we speak of Naval architecture, as well as use the word to denote the construction of edifices on land. It is, however, used in a more strict and special sense to indicate the building of such edifices as exhibit symmetrical arrangement and proper proportions of their parts, and are adorned by pillars, entablatures, arches, and other forms of embellishment. Architecture may be regarded from an artistical, a scientific, and a utilitarian point of view. In the first case it may be considered as a means of giving external form and sensible expression to mental conceptions or ideas, thus forming a branch of æsthetics. From the scientific point of view it consists of a knowledge of certain laws of physical nature and a power of calling them into play or counteracting their operation, and is a branch of mechanics. In the third sense it is a practical art, which has for its object the application of the principles which the art embraces.

Although architecture doubtless had its rise in the construction of buildings for the purposes of shelter and defence, yet it is no less certain that it is indebted for its rapid advancement and its ultimate perfection to the religious feelings of mankind. It is in the temples we look for beauty of design, for appropriateness of embellishments, for grandeur, ideality, and magnificence. Had it not been for religion, architecture would never have risen to that eminence which it so early attained in the sacred edifices of the ancients, which have attracted such universal admiration. It is to the temples, then, we must look for the progress of a people in this great art; by them we must compare nations as to their advancement in skill, taste, and science, as well as in the general progress of civilisation. It was in Greece that this department of art arrived at its greatest excellence, insomuch as to form a new era, which, for pure and chaste grandeur, has never been surpassed. The Romans, who were also skilled in architecture, aimed rather at utility than ornament. Many of their buildings are worthy of admiration for some degree of beauty which they possess, but they do not equal those of Greece in purity and grandeur. The Greeks were lovers of art for its own sake: the Romans for the sake of the benefits it afforded them. While the Greeks may claim the palm for purity of taste, the Romans take precedence in utility and variety of construction.

Building Materials.

The materials which are most largely used in the construction of buildings are brick or stone for the carcass or shell, tiles or slates for roofs, cement or lime for fastening bricks or stones together, and iron and wood for internal supports and fittings. Besides these, lead, zinc, glass, paint, plaster, paper-hangings, nails, locks, hinges, door-handles, stoves, gas-fittings, and other articles of an accessory kind are used, so that building includes or gives encouragement to a very large number of industries. The choice of material for the exterior of a building is regulated by the character and intended uses of the structure about to be erected, the kind of material most easily procurable, or the means of those on whom the cost of the work is to devolve. In districts where suitable stone abounds, that material is most commonly employed, but its use is by no means confined to the localities where it is found, since by means of railways it can be quickly conveyed from the quarries whence it is obtained to places far distant from them.

Bricks are generally employed in districts where the nature of the soil favours the manufacture of them, and in cases where considerations of convenience and economy render the use of them preferable to the use of stone. In treating of the various materials to which we have referred, we shall give the first place to bricks.

Bricks and Brickmaking.—Brick is an artificial kind of stone, composed in general of clay and sand or coal-ashes well mixed together, tempered with water, and formed into small oblong blocks, and then dried in the sun and burned to a proper degree of hardness in a kiln, or in a heap or stack denominated a clamp. The antiquity of bricks seems to be coeval with the

THE OAK.

THE HORSE-CHESTNUT.

THE NORWAY FIR.

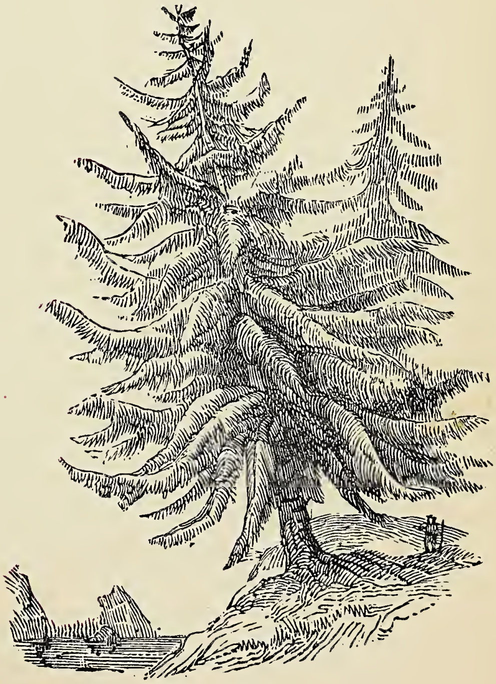
THE CEDAR.

TIMBER TREES.

THE ALDER.

THE MAHOGANY-TREE.

THE SILVER FIR.



THE LARCH.

TIMBER TREES.

first edifices erected after the Deluge. Abundant evidence of the very early use of bricks is presented by the ruins of Babylon. Remarks on this point will be found at pages lv. to lvii. of the Introductory section of this work. The first thing to be considered in the manufacture of bricks is the clay or soil which forms the staple of the article. The earth selected for brickmaking should be of the purest kind. In Great Britain bricks are chiefly made either of stiff clay, or of a hazelly-yellowish coloured fat earth called loam. The former produces hard red bricks, the latter is mostly found near London, and gives a grey-coloured brick, which is not so hard as the red brick, but is equally durable. For making such bricks as will stand the fiercest fires, Stourbridge clay, Farnham clay, and Windsor loam are esteemed the best. The clay for bricks is dug in the autumn, and exposed to the action of the winter's frosts, which pulverise the more tenacious particles and assist the operations of mixing and tempering. For the best bricks two or more years will not be found too long to submit the earth to the action of the atmosphere. In making up the heap for the season, the soil and ashes or sand are laid in alternate strata, each stratum containing such a quantity as the stiffness of the soil requires. The usual proportion is four parts of clay to one of ashes. Much judgment is required in this tempering operation. Besides ashes, sand, chalk, and breeze are employed. In the spring the mixture is turned over with spades, or pulled over with a long hoe. Water is added, and the mass is worked into a kind of paste. When it is sufficiently mixed it is removed in barrows to a pug-mill, which is moved by a horse, and consists of an iron hooped barrel in which the clay is cut and worked about until it is perfectly amalgamated. Before the invention of the pug-mill, this kneading process was effected by the treading of the workers, or the trampling of cattle. The masticated clay is forced through a hole in the bottom of the barrel, when it is cut off in pieces and laid on one side. It is now ready for moulding. A boy cuts off from the mass as much as he can carry in his arms and places it on the moulding table, where it is cut into pieces a little larger than the capacity of the mould. The moulder throws each piece into his mould, which is previously dipped into dry sand. He scrapes off the superfluous clay with a piece of wood, and disengages the brick from the mould by a gentle stroke on the back of the mould. The wet bricks are arranged in rows on a long board, and when they are sufficiently dry to be handled, they are turned. They are next piled in long rows or hacks to dry in the open air, and are so placed that air can pass between them. In showery weather they are covered with straw. The bricks are dry enough for turning in a few days, and in six or eight days are ready for burning. Bricks are burned either in clamps or kilns. In the method of burning by clamps or stacks, which prevails most near London, the bricks are piled up in rows containing from 500,000 to 1,000,000, with fuel interspersed among them, so that the whole mass may become burned. A clamp is sometimes three months in becoming thoroughly heated. Clamp-burnt bricks are the commonest kind. The best bricks, which are called Malms or Marls, and are more carefully made than the ordinary sort, are burnt in kilns, which are usually about twelve feet high, thirteen feet long, and ten and a-half wide, and will burn 20,000 bricks at a time. The bricks are set on flat arches, having holes in them, under which the fire is lighted. By this method the bricks are thoroughly burned in two or three days. Modern ingenuity has devised many modes of applying machinery to the making of bricks. The first step in this direction was made by the introduction of the pug-mill. In 1839 a machine was brought out by which the operations of kneading and moulding were combined. Numerous other brickmaking machines have since been produced. They are fed at one end with clay, which is moulded and delivered at the other end in the form of bricks ready for burning. Brickmaking by hand is still, however, carried on in many places. Bricks for building are commonly nine, four-and-a-half, and two-and-a-half inches in their three dimensions. The most usual varieties of bricks are marls, stocks, and place bricks. There are also buttress, capping, cogging, great, compass, concave, and feather-edged bricks; also Dutch or Flemish bricks for paving, and fire-bricks, which are used in the construction of furnaces.

Terra Cotta, which is employed for ornamental purposes in building, is, as its name indicates, a form of "baked clay." It was commonly used in Britain in the reign of Queen Anne. The use of it has been extensively resumed in recent years. It has been employed with admirable effect in the South Kensington Museum and other large buildings.

Tiles are used for roofing. They are composed of a material and made in a manner which place them in an intermediate position between bricks and coarse brown pottery. Roofing tiles are chiefly of two sorts: *plane tiles*, which are of a rectangular form and flat, and usually measure $10\frac{1}{2}$ inches by 6, and *pantiles*, which are bent in such a manner that when laid they form a groove. These are usually $13\frac{1}{2}$ or $14\frac{1}{2}$ inches long, and about 9 inches wide. Ridge tiles of a very ornamental character are made. Tiles are also used for pavements. The finer kinds of paving tiles are called encaustic tiles.

Stone.—An account of the different kinds of building stone, the places where they are procured, and the manner in which quarrying is carried on, is given in Chap. VI., Vol. I., pp. 201 to 211. Not only are buildings constructed of brick or stone: sometimes both materials are employed in the same structure. When buildings are intended to display a stone front, and when stone is too expensive to form the main substance of the structure, the walls are formed of brick or rubble, and are cased externally with a layer of stone called *ashlar*. The slabs of stone used for this purpose are generally from four to six inches thick. In *plain* ashlar the surface of the stone is smooth; *tooled* ashlar

exhibits a series of narrow parallel flutings; and *rusticated* ashlar has an indented surface, produced by cutting into the stone at the sides of joints. Various kinds of concrete and artificial stone have been and are used in building. Mr. Frederick Ransome, of Ipswich, has rendered great service by his inventions and productions in this department. In 1872 he succeeded in making stone by mixing lime and a natural soluble silica found in a rock forming a stratum of the lower chalk in Surrey, with sand and silicate of soda. Artificial stone can be moulded in the process of manufacture into chimney-pieces, balustrades, or whatever can be made of real stone.

Slate.—This material, which has in modern times so extensively come into use for roofing purposes as to greatly circumscribe the employment of tiles, will be found treated of at page 210, Vol. I. We may, however, add that slaters class the Welsh slates as follows:—Doubles, Ladies, Countesses, Duchesses, Welsh-rags, Queens, Imperials, and patent slate. The first-named two are small, Ladies are larger; Countesses are a gradation above Ladies, and Duchesses are still larger. Imperials are known by having their lower edges sawn, whereas all the others are chipped square. The patent slate allows of being laid on a rafter of much less elevation than any other kind of slate, and is considerably lighter, by reason of the laps being less than is necessary for the common sort of slating.

Cements are described at page 211, Vol. I., *ante.*

Stucco.—This term is indefinitely applied to calcareous cements of various descriptions which are used in building. A fine kind, made of gypsum or plaster of Paris, is used for cornices, etc. A coarser kind is also used for making floors, and for plastering the exterior of buildings. In the latter case the cement is mixed with oil, and, when well applied, it gives the appearance of stone to the surface. It keeps a building warmer, protects the brickwork, and takes paint readily.

Iron.—References to iron in its relation to building will be found at pp. 78 and 215, 216, of Vol. I., *ante*, and a full account of the nature, manufacture, and varied uses of it is given in Chapters III., VII., and VIII. of the same volume, so that we will do no more here than simply name it.

Lead and Zinc.—Both of these metals are used for roofs of buildings. The latter is now frequently used as a roof covering. It is not so heavy as lead, and is not so soon acted on by the atmosphere as iron. For information on lead mines and manufacture, see pp. 111, 112, Vol. I., *ante.* Zinc will be found treated of at pp. 119, 120, Vol. I.

Wood.—Timber, as wood used for building purposes is called, is largely employed in the construction of edifices. It is used for roofs, flooring, wainscoting, skirting, staircases, cupboards, doors, window-frames, etc. Generally speaking, fir, pine, or deal is the kind most extensively employed in Britain. This arises from its being cheaper and more easily worked than oak, beech, birch, and other kinds, which are used to some extent, and more durable than many other sorts. The kind of fir most generally employed in carpentry is distinguished by the name of Memel, which includes Dantzic and Riga. Norway, which includes Swedish, is much used for smaller timbers, and Dranton or Dram is suitable for flooring. American fir is much softer, but suits inside joinery work, such as panels and mouldings. What is termed in England white deal, and in Scotland pine wood, that is, fir deprived of its resinous part, is very durable when kept dry. It is much used in internal carpentry or joinery, but will not stand the weather. The red or yellow fir is the produce of the Scotch fir, which is common in the north of Europe. White fir or deal is the produce of several varieties of spruce fir. The Weymouth or white pine is a native of North America, and the pitch-pine is a native of Canada. Wood of good quality is obtained from the silver fir, which is a native of the mountains of Siberia, Germany, and Switzerland, and is common in Britain. Some account of the operations of felling and transporting timber may be acceptable here. The best time for felling is in midwinter and midsummer, for in the former the sap has ceased to flow, and in the latter it is expended in the production of leaves. In the forest districts of the Alps, of Germany and Norway, the modes of transporting timber are curious and interesting. When the trees are near to a stream, the woodmen cut them down, hurl or roll them into the stream, and let them float down to the sea, a lake, or any place where they can be easily disposed of. In cases where the forest is on a mountain or distant from a stream, slides have to be formed. These consist of troughs, constructed of six or eight fir trees, placed side by side lengthwise, so as to form a semicircular gutter. This arrangement is continued throughout the distance to be traversed. There was one of these troughs or slides t Alpnach, which was more than eight miles in length, and extended from an elevation of two thousand five hundred feet down to a lake. The velocity with which the trees descend is almost inconceivable. In Russia trees are drawn by four to nine horses each, and in some cases have to be conveyed nearly a thousand miles before a stream or lake is reached. It is sometimes two years after the timber has been felled before it reaches the consumer. The lumbering parties of North America and Canada fell and transport timber in a way combining in some degree both the Alpine and Russian methods. "Lumber" is a general name for timber in North America, and a lumbering party is a sort of joint-stock company of woodmen, who procure timber from the depths of the forest and bring it to market. The trees are cut down in the summer months, and are divided and shaped according to the purposes to which they are to be applied. If possible, the scene of operation selected is near a stream, which will work a saw-mill, and float the timber to market. During the autumn the felled trees are cut into logs or hewed with the axe into baulks and beams. When the winter has ar-

rived, the logs are dragged by oxen to the bank of the stream, where saw-mills of a temporary character are erected to cut up the logs into planks. In the spring the timber is floated. It is formed into rafts, according to the size of the stream. The timber sometimes floats three or four hundred miles. Some of the raftmen build rude huts for themselves on the rafts. Striking examples of the floating of timber by means of rafts are presented on the Danube and the Rhine. Some of the rafts are eight or nine hundred feet long, by sixty or seventy wide, and are composed of several layers of timbers or trees placed on one another, and tied together. The rowers and workmen on them amount to several hundreds. Huts are erected, and live animals and provisions are conveyed on the rafts, so that they look like floating villages. Timber, while seasoning, is sometimes piled up perpendicularly in an airy dry place, with proper interstices to admit a free circulation of air. Both rain and the excessive heat of the sun should be excluded, so that the timber may dry without shakes or fissures. Some persons, however, prefer to keep the timber as moist as they can. In some cases timber is scorched, steamed, or boiled, or smoke-dried. Various methods are employed to preserve timber which is to be placed in damp situations. They are distinguished as Kyan's, Payne's, Burnett's, and other patents.

Sawing.—Timber is in the first place sawed into planks. These are in general from one inch and a-half to four inches thick. If they are of less dimensions, they are called boards. The term planks is not applied to fir. This is cut into "deals," which are of various lengths, most commonly three inches thick, and seldom exceeding nine inches wide. These are cut down into various thicknesses, called boards or leaves. Timber is divided by vertical saws, worked by two men, one of whom stands in a pit. The subsequent sawing into smaller pieces is effected by hand-saws. Machinery is largely employed in sawing. Two or more saws are fixed together in an upright frame, and at such distances apart as the thickness of each plank or board requires. Steam power is used to drive the saws, against which the log is gradually forced. Circular saws are often used, against which the timber is forced as they rapidly revolve. These are largely employed in producing veneers or exceedingly thin pieces of wood. (See page 339, Vol. I., respecting the manufacture of saws.) Among the kinds of wood not already mentioned, which are used for building or making furniture, etc., are mahogany, alder, plane, sycamore, chestnut, ash, elm, walnut, teak, poplar, cedar, larch, besides various rare hard foreign woods, which are valuable for special purposes.

Glass.—This material was little if at all used by the ancients for building purposes, and its introduction has been productive of comforts and elegance to which the most refined of the Greeks and Romans were strangers. Their oiled paper, transparent horn, talc, shells, and linen, would now appear miserable expedients even to peasants. Glass is not only used for windows of the ordinary kind. In recent times it has come to form one of the principal materials of which certain structures are composed. A notable example of this is afforded by the Crystal Palace at Sydenham ; other instances are to be found in the vast roofs of railway terminal stations such as the Midland, Great Northern, and others which consist entirely of iron and glass. For an account of the manufacture of glass, see pp. lxv., lxvi. Introduction, and Chapter XIV., pp. 546 to 560.

Paint.—Painting forms an important part of the work which is connected with building. Paint is employed for the preservation of wood or other materials which are used in building, and for the embellishment of edifices, both internally and externally. Most of the paints used for ordinary purposes are composed of the colouring matter, white lead, boiled linseed-oil, and siccatives or driers, such as spirits of turpentine, sugar of lead, and litharge. White lead forms a colour by itself ; other white pigments are prepared from the oxide of zinc and the carbonate and sulphate of barytes. Colours are made from sienna, venetian, red ochres, umber, and other earths, and from chrome, yellow, vermilion, verdigris, verditer, Prussian blue, and other metallic compounds. Many colours are formed by mixing two or more colours already obtained. Artistic painting is sometimes resorted to for the decoration of the ceilings and internal walls of buildings, regular pictures being formed on them either in fresco or distemper. *Fresco* is a mode of painting on fresh or damp plaster. In *distemper* the colours are laid upon dry plaster instead of wet. The former process is a difficult one, and requires to be accomplished with great rapidity, every portion of the picture has to be completed on the day on which it is commenced. When painting is done *in distemper*, the colours are mixed with the white of eggs or some proper glutinous substance, and not with oil. Walls are sometimes painted *in encaustic*, in which method wax and gum form the vehicle for laying on the colours, which are fixed by means of heat. Polished and carved woodwork and tapestry hangings are also among the means employed for decorating the walls of rooms, but paper-hangings are in most general use for this purpose.

Paper-hangings.—The commonest kinds of paper-hangings are formed by a very simple process. It consists in having the pattern cut out in a sheet of tin or leather. This is laid on the paper, and a brush dipped in liquid colour is passed over the perforated sheet and the holes of the pattern. This constitutes *stencilling.* In preparing the more costly kinds, the patterns are printed in outline from wooden blocks, cut in relief, and the device is filled in by painting with a pencil. The art thus combines "paper-staining" and a variety of "colour printing." Paper-hangings are printed in lengths of twelve yards each, one of which is called a "piece." As regards the patterns, it is obvious that scope is afforded for almost infinite variety and great artistic skill in designing them.

Inlaid Floors.—These may be mosaic or tesselated, in which case the materials employed are

stone tiles or enamel laid in cement. Delicate pictures are in some instances produced by mosaic enamel. Another kind of inlaid flooring is *parquetry*, which consists of pieces of wood so shaped as to produce an elegant pattern.

Building Trades.

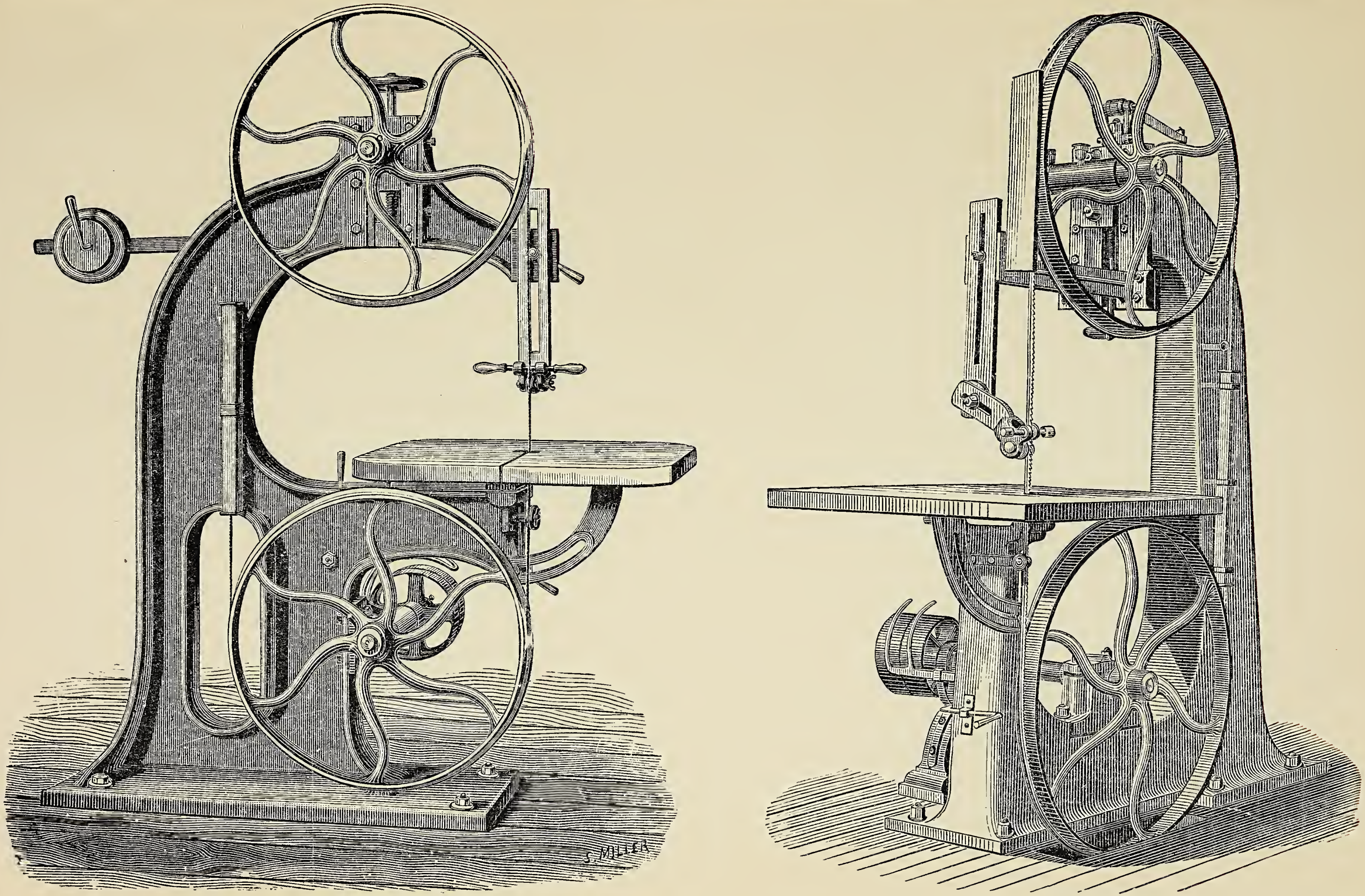
Building is the art of constructing a fabric, as a house, bridge, ship, or other structure. Like the term architecture, the word building has a general and also a special or limited meaning. It is used here to signify the art of putting together materials so as to form a dwelling or some other edifice. The business of house-building comprises the execution of work by persons of several different trades, of which some account follows.

The Architect.—According to the etymology of the word architect (*Gr. archos* chief ; and *tekton*, a fabricator), it denotes the principal person connected with the work on which he is engaged. In building, his work comes first in the order of time, and is of great importance in connection with it. He endeavours to realise the wishes of the proprietor of the intended structure as to the internal arrangements and external appearance of it. To his taste, judgment, and science, must be left the selection of the best style and plans for carrying out the ideas of the owner. It is his business to draw plans and make out specifications of the work to be performed. A thorough knowledge of mathematics is necessary. He should also be accomplished in arithmetic, and expert in perspective drawing. The drawings necessary in the construction of an edifice are :—Plans of the several stories, elevations of the façades, a transverse and a longitudinal section, at least, horizontal and vertical sections of all the difficult parts, and a detail of all the mouldings and ornaments at large. It will thus be seen that the profession of the architect demands much imaginative power, great artistic skill, and a practical knowledge of details. He needs to be acquainted with the qualities and values of different kinds of materials, and the prices which should be paid for work done, and makes out the contracts for the same. It is also part of his business to superintend the work while it is in progress, and see that the plans are carried out, and that the contracts are fulfilled. In this portion of his task he is assisted by a *clerk of the works*, who is stationary in the building, gives directions, keeps a register of the workmen's time, examines the work, and makes reports. When the builder's work is completed, the architect examines and checks his account, and, if satisfied as to its correctness, gives a certificate, which is the warrant for payment by the employer. The emoluments of the architect are generally five per cent. on the amount of money expended.

The Builder.—Strictly speaking, a builder is one who builds. He is also one whose business it is to undertake to get building done, or contract to rear up edifices. The builder either undertakes to execute work according to schedules of prices which apply in different trades and departments, or he contracts for the whole work for a stipulated sum. It is the builder's duty to carry out the plans of the architect, and the specifications which have been agreed upon. He provides the necessary materials, and engages the requisite workmen. In many instances the builder is proprietor, and merely carries out his own plans. Many of the large contractors or builders employ machinery worked by steam power in the manufacture of various parts of buildings. This greatly facilitates their operations, enables them to execute work more cheaply, and increases their rate of profit.

The Bricklayer.—The meaning of this designation is too plain to require any definition. In bricklaying the first thing to be attended to is to dig trenches for the foundation. This follows after the ground has been laid out or excavated for kitchens or vaults in the basement, where a cellar story is required. Foundations are generally formed of concrete, that is, a mixture of pebbles, lime, and cement. In laying the foundations of walls, the first courses are always laid broader than the wall intended to be carried up. These courses are called footings, and the projections are called set-offs. There are generally two inches in each projection. In laying bricks, there are four kinds of bond, viz., English bond, Flemish bond, Herring bond, and Garden-wall bond. English bond consists of a row of bricks laid lengthwise, and crossed by a row with its breadth in the length, and so on. The former of these layers are called "stretching courses," and the bricks forming them "stretchers;" the latter are "heading courses," and the bricks "headers." Flemish bond consists in laying a header and a stretcher alternately in the same course. The herring bond is formed by placing the bricks at an angle of forty-five degrees, and reversed in the alternate courses. Garden-wall bond consists of three stretchers and one header in nine-inch walls. In forming arched work, each radiating line of bricks is wider at the top than at the bottom, and the bricks require to be brought to the proper slope by means of a guage. Arches are constructed on wooden frames called centerings. In straight arches the camber slip answers the purpose. The most difficult work for a bricklayer to execute is the groining or intersection of arches in vaults, where every brick has to be cut to a different bed. Walls vary in thickness from half a brick to four bricks, that is, from four and a-half inches to three feet. The bricklayer is paid for his work at so much a rod or pole, that is, a surface of $16\frac{1}{2}$ feet square, and a thickness of one brick and a-half. Mortar and cement which are used in fixing brickwork have been already treated of. (See *ante*, p. 211, Vol. I.)

The Mason.—Masonry is the art of preparing, laying, and fixing stones used in building. It is of three sorts—viz., cut masonry or plane ashlar, which consists of fair cut stones, as in the faces of the superior kind of buildings ; hammer-dressed masonry, in which stones are squared and picked by the hammer ; and rubble masonry, composed of stones merely axed on th



WATSON'S BAND-SAWING MACHINES.

face, and placed according to circumstances. In Norfolk and Suffolk large flints are used. They are split, and the walls are made to present an even face with good joints. Mortar and cement are used for attaching stones together. Great architectural beauty can be and is attained in buildings in which stone is used. This arises from the suitability of stone for being carved or sculptured into various forms. Grand examples of this are presented in the cathedrals of England and elsewhere, and in other magnificent structures. The roof of Henry the Seventh's chapel, Westminster, is a specimen of the most enriched and delicate sculpture. (See p. 202, Vol. I., on Ancient Masonry, and pp. 201 to 210, Vol. I., on quarrying building stone.)

The Carpenter.—The works done by the carpenter in the general construction of buildings are the preparation of piles, sleepers, and planking, or other large timbers in the foundations, centring to vaults, wall-plates, lintels, and bond timbers, naked flooring, partitioning, roofing, battening to walls, ribbed ceilings to form vaulting for lath and plaster, etc. Finishings and ornamental work are called *joinery*. The operations of joinery consist of forming surfaces of various kinds, also of grooving, rebating, moulding, mortising and tenoning, and of joining two or several pieces together so as to form a frame or solid mass. As has been already intimated, steam-worked machinery is largely employed in the production of joiners' work, such as doors, sashes, balusters, etc. The carpenter and joiner are, however, still indispensable for the work of fitting and fixing the articles thus produced. To enumerate all the kinds of work which are executed by carpenters and joiners, and the names of the various timbers which are used and the articles which are formed, or the ends which are attained by their labours, would require a larger amount of space than we can command. This general survey of the subject must therefore suffice.

The Painter.—In painting, the first thing necessary is to clear off all dirt and dust by means of a brush. The painter next stops up all holes with putty, and then paints over these and knots in the wood with turps, or turpentine mixed with red lead. He then applies the first coat, and when this is dry rubs it over with pumice-stone. The number of coats varies from three to six. When painting is finished with a coat prepared with oil of turpentine which takes off the gloss, it is called flatting. Painters who produce imitations of the grains of wood are called grainers; others are marblers. Wood is sometimes stained in a manner which shows its natural grain. Both painted and stained surfaces are varnished.

The Plumber.—This artificer is so named from *plumbum*, lead, the material on which he works. His business consists chiefly of laying and joining the lead which is used in the sheet form for roofs or gutters, and in fixing and soldering pipes in connection with cisterns or pumps, etc. In soldering, soft solder, which is a compound of equal parts of tin and lead, is employed. The plumber lays a little resin or borax on the joint, and the heated solder is then poured on it, and the joint is finished by rubbing it with a red-hot glozing iron and by filing.

The proper execution of plumbing or plumbery is very important from a sanitary point of view as regards trapping drains, and making the right sort of connections for cisterns, sinks, baths, and ventilation pipes. Slating, tiling, plastering, whitewashing, paperhanging, glazing, and gasfitting are operations so well understood that they need not be described. They are, however, deserving of mention here, as like the other trades which have been referred to in this section, they give employment to many persons and conduce much to the comfort of the community.

Furriery and Leather, and its Uses.

Although the skins of animals are not, in modern times and civilised countries, used for clothing in the same state as that in which they were worn in ancient days, and are still in some parts of the world where men are in a more or less barbarous condition, yet they furnish the materials for making articles of dress and other things which are useful to mankind. The wool of the sheep, alpaca and llama, and the hair of some species of goats, supply instances of this, and others are afforded by the hair of fur-bearing animals, and the various kinds of leather which are made of skins of different sorts.

Fur and Furriery.—The principal kinds of fur which are known in commerce are ermine, stoat, sable, fiery red and silver fox, nutria, sea otter, seal, bear, beaver, racoon, badger, minx, lynx, muskrat, rabbit, hare, squirrel, opossum, chinchilla, and kangaroo. Furs are obtained chiefly from Russia and North America. The Hudson's Bay Company, which was established in 1670, derives its income almost exclusively from the trade of procuring and supplying furs. Nearly all the skins are shipped from Rupert's Land. There are two methods by which furs are manufactured into a state fit for use—viz., felting and dressing. In felting, the furs which are mostly operated on, are hare, rabbit, bear, and nutria. After the furs have been cleansed and flattened, the longest hairs are removed by shears, and after that the true fur is removed from the skin or pelt by a sharp knife, something like a cheese-cutter, or in a cutting machine. The fur having been removed from the skin, is separated into different qualities. Felted fur is chiefly used in hat-making. Dressed furs are those in the manufacture of which the fur is not removed from the pelt. They are steeped and scoured in a bath of bran, alum, and salt, to remove greasiness from the pelt, and are then cleaned with soap and soda to remove oiliness from the fur. In this process the pelt is converted by the action of the alum into a kind of kid, or tawed leather. The skins being irregular in shape and differing in colour, require to be cut up into pieces and sewn together so as to be suitable for the garments they are intended to form, or other purposes for which they are to

be used. In ermine, the black patches are the tails of the animals sewn on.

Leather and its Uses.—The manufacture of leather is a department of industry of great importance. It gives employment to a very large number of persons in several branches, including tanners, curriers, dressers, shoe, glove, and harness-makers, saddlers, etc. There are three methods of preparing hides or skins. They are known as tanning, tawing, and shamoying. The latter two are also spoken of as leather dressing. Leather consists of the skins of animals after they have been chemically changed by one or other of the processes just named. In *tanning*, the change is effected by means of a substance residing in several vegetable matters called tannin, which unites with the gelatin of which the skins chiefly consist, and so forms the substance called leather. Oak bark is the substance most extensively used in tanning, though many others are made use of. Among these are the bark of the willow, alder, larch, birch, cork, and Spanish chestnut. Sumach, catechu, terra japonica, valonia, divi divi, myrobalams, boomah nuts, kino, myrtle, and wild laurel leaves, tormentil and mangrove roots, and pulverised heath. The chief animals whose skins are converted into leather are oxen, horses, buffaloes, pigs, sheep, calves, lambs, goats, dogs, rats, and seals.

Tanning.—In describing the process of tanning, we will commence with the skins of the larger animals, to which the name hides is given. After the horns and all superfluous matter have been removed, the hide is stretched over a convex beam called a "horse," and is scraped with a long knife to remove everything adherent to the inner surface, except the cutis or true skin. The next thing to be done is to remove the hair from the outer surface. To effect this the hide is steeped in lime water for several days, or it is placed in a heated chamber. By these means the hairs become loosened, and are easily removed by scraping. When the hide is brought to a tolerably clean state, it is steeped in a weak solution of sulphuric acid and water, which has the effect of thickening the hide and opening the pores for the reception of the tannin. This part of the process is technically called "raising." The hides are next soaked in pits containing a mixture of water, and bark ground to small fragments in a bark-mill. Sometimes layers of bark are placed between the hides; in other cases the hides are steeped in a bark liquor, called "ooze." They are turned over day by day for a period extending from four months onwards. They are afterwards laid away in lapping pits containing a strong solution of bark. Here they remain from four to nine months. The usual time of immersion in the tan-pits is from twelve to eighteen months. All this time the tanning ingredient is working its way slowly into the pores of the hides, and when it has reached the centre the tanning is completed. After this the hides are hung up in an airy loft or drying-room. They are also compressed by beating, by pressure with a steel instrument, or by rolling. In connection with tanning sheep-skins, to produce basils, etc., very great care is taken to cleanse the "pelts," as they are called, and also to soften them and swell their substance. The actual tanning of the skins is carried on in the same way as with hides. Many processes have been invented, and, to some extent, adopted for shortening the time occupied in tanning, but the general practice is that which has been here described. Many of the thin skins which are prepared for ornamental purposes, are tanned with sumach, which consists of the leaves of a tree of that name which grows in the South of Europe. Morocco, which is made from goat-skins, is prepared in this way.

Tawing.—This is the name which is applied to the process by which the skins of sheep, lambs, and kids are converted into soft leather. In this case the skins are soaked, scraped, limed, and unhaired much in the same way as for other purposes; but after this, instead of being immersed in tannin, sumach, or any other vegetable astringent, they are rotated rapidly in a barrel containing alum, salt, and yolk of egg. If the skins are not intended to be white, other materials, including pigeons' and dogs' dung, are employed. When the skins have imbibed the ingredients to which they are subjected, they are dried, and after that are forcibly drawn over the edge of an upright metal plate—a process which imparts to them that delicate softness which distinguishes kid.

Shamoying.—By this process, which is also called "Shammying," the skins are prepared with oil. This kind of leather takes its name from a fine soft leather which is made from the skin of the chamois goat, but other skins are prepared in the same way. In preparing the skins they are steeped, limed, scraped, etc., as usual, and are then sprinkled with oil and beaten with heavy mallets, which work up and down in a kind of trough, which is called a fulling-stock. They are thus beaten until the oil is completely worked into the pores of the leather.

Currying.—The thinner kinds of tanned leather pass into the hands of the currier, whose business it is to give them a suppleness which they would not otherwise possess. For this purpose the tanned skin is moistened in water and beaten with a wooden mace. It is afterwards placed on a sloping board, and scraped or shaved until any superfluous parts of the thickness are removed. After this the leather is again soaked in water, and rubbed on the outer side with pumice or gritstone. It is further rubbed on both sides very forcibly, and for a considerable time with a hard block of wood, called a pommel, the surface of which is cut into ridges or grooves. The skins are again scraped to bring them to a uniform thickness, and after that a composition of cod oil and tallow is rubbed over the leather. Blacking and polishing, if required, finish the routine.

The Kinds and Uses of Leather.—The leather made from the hides of the larger animals is used for the soles of boots and shoes, and all purposes for which leather of a thick and durable

kind is required. South America furnishes the hides of which the thickest leather is made. The hides of horses are generally used for making harness. A hide of leather with the cheeks, shanks, and belly pieces pared off, is called a butt, and the pieces which are cut off constitute the offal. Calf skins and kip skins, which are the skins of beasts older than calves, but not full grown oxen, are chiefly used for the upper leather of boots and shoes. The Cordovan leather, which was first made of goat skins at Cordova, in Spain, is used for the upper leathers of boots and shoes of the lighter kind. Shoemakers get the name of cordwainers from Cordwain, a corruption of Cordovan. Morocco leather, which is made of goat skins, is used for coach-linings, chair-covers, bookbinding, etc. An imitation Morocco is made of sheep skins split in two thicknesses. Roan prepared from sheep skin is used for women's shoes, slippers, and common bookbinding, and skiver also from sheep skin is employed for hat linings, pocket-books, etc. Russia leather is made of goat skins, and owes its peculiar odour to the birch bark with which it is tanned. Shagreen is produced by pressing seeds into skin obtained from the back near the tail of horses, mules, etc. It was formerly much in demand for ornamental purposes. Kid, lamb, dog, and rat skins are used for making gloves. Seal skins are manufactured into patent or enamelled leather by varnishing their upper surface. Hog or pig skins are chiefly made into saddles for horses. Walrus, hippopotamus, and porpoise hides are tanned and used for various purposes. Kangaroo skins are employed in making gentlemen's dress boots. Buck and doe skins are used for riding-gloves, breeches, gaiters, and wash-leather.

Clocks, Watches, and Chronometers.

All the instruments named in the heading of this section come under the common designation of timekeepers or measurers. According to the literal meaning of the words *chronos*, time, and *metron*, a measure, of which the term chronometer is compounded, any clock or watch is really a chronometer, although the name is specially applied to a particular kind of timekeeper, just as all time measurers are timepieces, although that name has come to be understood to mean a clock which indicates the time but does not strike. Time may be defined as duration measured or divided, or, according to John Locke, it is "the consideration of duration as set out by certain periods, and marked by certain measures or epochs." The word time is sometimes employed in the same sense as duration, but it is most generally used to denote a portion of duration in accordance with the signification of its root, *temno*, to cut, hence a piece cut off. The art or practice of measuring time is called horometry; and the science which treats of the construction of machines for the measurement of time is called horology. The earliest means employed for measuring the smaller portions of time seems to have been the gnomon, the invention of which Herodotus ascribes to the Babylonians. It consisted of a staff or pillar fixed perpendicularly in a sunny place, the shadow of which was measured by feet upon the place where it fell, and thus time was computed. In modern days these contrivances are called sun-dials. Among the ancient Greeks a time measurer was in use called the "Clepsydra," or water-clock. Clepsydras were so arranged that given quantities of water should flow out of a vessel in certain times. In the hour or sand-glass, sand is employed for the same purpose.

Clocks.—It seems to be an impossibility to state exactly when and by whom clocks were invented. The earliest of them is ascribed to the 11th century. They were early known in England. In 1288 a tower containing a clock was erected opposite Westminster Hall, London. There is good reason to believe that clocks were not the invention of any single individual, but the result of a series of inventions made at different times by different persons. In the common house clock and large clocks which are placed in turrets or towers the measurement of time depends on the movement of a system of wheels derived from the descent of a weight by the force of gravity, and regulated by a pendulum. The motion is communicated from one wheel to another by means of teeth and pinions until the two axes are moved, which carry the hour and minute hands round the dial or clock face. A pendulum clock which was fixed in the turret of St. Paul's, Covent Garden, in 1642, was, it is said, invented by Richard Harris, and is stated to have been the first of its kind in Europe; but the first person who investigated and established the mathematical theory and properties of the pendulum was Christian Hüyghens, a Dutch philosopher of the 17th century. A very important part of the machinery of a clock is the escapement, which connects the wheel-work with the pendulum, and is so called because it allows a tooth to escape at each vibration. A new escapement, called the anchor or crutch escapement, invented by Dr. Hooke, was practically introduced into clock making by Clement, a London clock maker, in 1680. This superseded the old crown wheel which was adopted by De Wyck, a German who lived in the 14th century. In 1715 George Graham introduced the dead beat or repose escapement, which has now for more than a century and a-half been considered the best practical clock escapement. The striking part of a clock consists of a separate train of wheels, moved by a separate barrel and weight. These move a hammer intended for striking on a bell. Two kinds of striking parts are now in use. These are termed "rack" striking work, and "count wheel" or "locking plate" striking work. Up to the close of the 15th century the motive power in clocks was always obtained by means of weights, but when it was found that a coiled spring acting independently of position would answer the same purpose, it became obvious that time-pieces might be rendered portable, and this fact soon brought active and ingenious minds to bear upon the subject. Springs and their action will be found treated of in connection with the description of watches.

Watches.—A watch is a small portable machine for measuring time, the construction of which is essentially the same as that of a clock, except that the moving power is obtained from the elastic force of a coiled spring instead of from a weight, and that the movement is regulated so as to be isochronous by a balance and balance spring instead of a pendulum. The spring is coiled up in a barrel. Its inner end is fixed to an immovable spindle which forms the axis or arbor of the barrel around which it is coiled, and the outer end is fixed to the inside of the barrel. By its tendency to uncoil itself, the spring sets the barrel in motion. A piece of machinery called a fusee is employed to correct the variations in the force of the spring and equalise the power exerted upon the train. The fusee is a cone with a spiral groove connected with the barrel by means of a chain. In winding a watch this chain is wound off the barrel on to the fusee, and by the same operation the mainspring is coiled round its arbor. The gradual uncoiling of the spring moves the fusee, which communicates movement to the watch train. In watches the movement of the wheel train is regulated by the balance wheel, which is made to vibrate isochronously by the action of the balance spring, or hair spring as it is called on account of its extreme fineness, and by the escapement of which there are several kinds. The verge escapement is vertical, and derives its name from the spindle or arbor, also called verge, on the pallets of which the teeth of the escape wheel, which is also placed vertically, work. Another kind of escapement is the horizontal, which is the one used in most foreign watches. In this the escape wheel acts horizontally to the axis of the balance. The lever escapement is that which is used in most English watches. In it the scape wheel and pallets are exactly the same as in the dead escapement in clocks. The pallets (the two pieces which receive the immediate impulse of the balance wheel) are set on a lever, which turns on their arbor. The expression "jewelled," applied to a watch, refers to jewels which are used for pivots to play in them, because they do not wear away as metals do. A repeater is a watch that strikes the hour on a spring being touched. The keyless mechanism to a watch is one of the great modern improvements in watch work. It does away with the old-fashioned key; the watch being wound by turning a knurled knob placed on the handle or bow. Benson's Marking Chronograph is a highly ingenious and useful invention. By means of it the duration of a race or any rapid performance is not only indicated by the movement of a long extra seconds hand, but can be marked with ink upon the dial by pressing the button of the pendant.

Chronometers.—A chronometer is just a large watch fitted with all the contrivances which experience has shown to be conducive to accurate time-keeping, viz., the cylindrical balance spring, the detached escapement, and the compensation balance. The name is given principally to time-keepers which are used for determining the longitude at sea. Marine chronometers are always set horizontally in a box in gimbals, an arrangement which keeps them horizontal, whatever the motion of the vessel may be. In the compensation balance the circumference of the wheel is made of two metals, generally steel and brass, having different rates of expansion soldered together, the more expansible, which is usually brass, being on the outside. The compound ring is cut through in two or more places, and is weighted at opposite points. When exposed to a high temperature the ring expands, but owing to the unequal dilation of the metals each segment assumes a sharper curve, whereby its centre of gravity is thrown inwards, and the expansive effect is completely compensated.

Clock and watch making in England is chiefly carried on in Clerkenwell, London. Watch movements are generally made at Prescott, and other places in Lancashire. An ordinary London watch passes through more than a hundred hands from the beginning to the finish of its manufacture. Swiss or Geneva watches have long been celebrated, but though they are minute and delicate, and cheaper than English watches, they do not equal them in strength and accuracy. At Waltham, Massachusetts, and other places in the United States of America, watches are extensively produced, the works of which are made by machinery. It is claimed as an advantage in these watches, that they are made on the interchangeable principle, so that if one piece should break it can be replaced by a new one exactly like it. It is also pointed out that as there are 638 fewer pieces in these watches than in English watches, the wear and tear and cost of repair are lessened. The fusee and chain are among the pieces which are dispensed with in Waltham watches. This change is advocated on the ground that there is greater simplicity of action, less friction in the transmission of motive power, increased facility for using a lighter and more uniform spring, and more room for play in the other parts of the movement.

Philosophical Instruments.

So numerous are the instruments which are employed for scientific and philosophical purposes, that we can do little more than merely mention the most important of them, which, without further preface, we proceed to do.

These instruments may be classified as mathematical, astronomical, optical, pneumatic, electrical and magnetic, chemical, and meteorological.

Mathematical Instruments.—In a general way, the expression mathematical instruments is used to denote pieces of mechanism which are used to measure magnitude or quantities, or aid other instruments in bringing about such measurements. Among these may be included the sliding rule and Napier's rod, which are used for aiding calculation, and compasses, the geometric pen, and the pantograph, which are employed in drawing. No part of the labours connected with the construction of philosophical instruments is more delicate than that of "graduation" or marking the degrees on circles,

sextants, quadrants, verniers, etc. In this department great celebrity was gained by Ramsden, who, about the year 1766, invented a dividing machine, by which instruments could be graduated more quickly, cheaply, and accurately than formerly. Further improvements have since been made.

Astronomical Instruments.—By far the larger number of these are intended to determine the altitude of a heavenly body above the horizon, the direction of a body with respect to the meridian, or both of these combined. The transit instrument, the altitude, and azimuth circle, the transit level, the reflecting circle, the level collimator, the repeating circle, the zenith sector, the equatorial, the mural circle, the theodolite, and the sextant, all have some such object in view. Most of them comprise a telescope as a chief feature, the other portions of the instruments being devoted to the means of measuring accurately the position of objects viewed by it. There are numerous instruments which, though not immediately astronomical in their application, have an intimate relation to the requirements of the science of astronomy by aiding in the determination of points essential to correct observation.

Optical Instruments.—The word optical is derived from the Greek word *opteo,* meaning I see, hence it means relating to vision and light. Lenses, spectacles, telescopes, microscopes, magic lanterns, and a great many other instruments are comprised among those which are called optical. A piece of glass may be said to be the mainspring of all the great optical discoveries. The invention of the telescope illustrates the optical power of glass when curved in a particular manner. Lenses, we may premise, are pieces of glass having one or both sides convex or concave. They are employed to concentrate or change the direction of light. A concave lens renders objects smaller, but more distinct to near-sighted persons; a convex lens renders objects larger and clearer to off-sighted persons. Two lenses, either both convex, or one convex and one concave, when placed at a certain distance apart, give the power of magnifying the apparent dimensions of objects to a great extent. It is believed that Jansen, a spectacle maker, invented the microscope about the year 1590, and that this was one of the means of turning men's minds towards the telescope. Galileo formed a telescope which caused a great sensation. Newton, Gregory, the Dollonds, Herschel, and others, greatly improved on the earlier instruments.

Telescopes are refracting or reflecting. In the refracting kind the rays of light passing from the object are refracted by two or more lenses before reaching the eye. Reflecting telescopes receive the rays on a curved reflector called the speculum. The rays are conveyed to the eye through an eye-piece. The microscope and telescope differ chiefly in their uses; the former is used to view and magnify small objects close to the eye, while the latter is used to view large objects at a distance, and thus apparently bring them nearer. The magic-lantern, the camera, the kaleidoscope, and the spectroscope may be mentioned as being ingenious and interesting optical instruments.

Pneumatic Apparatus.—The air-pump is the principal instrument which is used in connection with pneumatics, or the science which takes cognizance of the pressure and movement of the air. It helps to demonstrate the reality of air by supplying the power to weigh, divide, rarefy or condense it. The object of the air-pump is to draw out the air from a glass receiver or other vessel by means of a pump and a system of valves, so as to be able to institute experiments on air. The Magdeburg hemispheres and the pneumatic bellows are familiar examples of pneumatic apparatus.

Electrical and Magnetic Apparatus.—A full description of the instruments which are used for conducting electrical experiments, and of the important machines in which electricity and magnetism are utilised, will be found in Vol. II. of this work, under the head of "Electricity and its Appliances."

Chemical Apparatus.—The instruments relating to chemistry are very numerous. They include lamps, stills, alembics, sand-baths, water-baths, pneumatic troughs, alkalimeters, blow-pipes, jars, and other vessels for liquids and gases; crucibles and melting-pots, tubes and pipes, flasks and funnels, crystallising and evaporating vessels, retorts and receivers, scales and weights, pestles and mortars.

Meteorological Instruments.—One of the most useful of these is the thermometer. In its usual form, as planned and named after Fahrenheit, it is a glass tube terminated at the bottom with a bulb containing mercury, and temperature is determined by the height to which the mercury rises in the tube. There is a graduated scale placed at the back of the tube, on which are numbers that afford the means of recording the height of the mercury. In some thermometers spirits are used instead of mercury. The expansion of solids by heat has given rise to various mechanical instruments for the measurement of temperature. Such are the pyrometer of Professor Daniell and the thermostat of Dr. Ure. The barometer, according to its name, signifies a measurer of weight. It consists generally of mercury contained in a vertical tube, so circumstanced as to be acted upon by the pressure of the atmosphere at one end, but shielded from it at the other. The height to which the mercury rises is made to indicate the degree of atmospheric pressure. In aneroid barometers the pressure of the air is measured, not by the use of liquid or quicksilver, but by means of a small circular metal box nearly exhausted of air. The anemometer or wind-gauge, the hygrometer for determining the degree of moisture in the air, the actinometer for measuring the intensity of heat in a sunbeam, and the cyanometer for measuring the degree of blueness in the sky, are other meteorological instruments.

India Rubber, Gutta Percha, etc.

India rubber, or caoutchouc, is the solidified

milky juice of certain tropical plants, the largest supply being obtained from the *Ficus elastica*, found in Assam, and from other trees growing in Java, America, Guiana, Brazil, and the islands of the Indian Archipelago. It would be impossible here to enumerate all the purposes for which it is employed. Its use for bands, tubes, and water-proofing cloth are well known. Vulcanised india rubber is caoutchouc combined with sulphur. In this state it is much harder and more durable. Ebonite or vulcanite, which is a black, hard elastic substance, is formed by combining sulphur with india rubber at a high temperature. It is largely used for making combs, door handles, and numerous other articles.

Gutta percha, which was first brought into notice by Dr. Montgomery in 1843, is the juice of a tree, and is chiefly obtained from the *Isonandra Gutta*, which grows in the Malay islands. It is a tough and inelastic substance, and is much used instead of leather. Being plastic at 212° it is largely employed by electrotypers, and can be moulded into picture frames, ornamental mouldings, inkstands, etc. It is insoluble in water, and a good insulator, and is hence used for water-pipes, coverings for submarine telegraph cables, and for making carboys, bottles, baths, etc., for chemists. A kind of floor-cloth, called Kamptulicon, is made by working ground cork with india rubber. It deadens sound, prevents cold feet, wears a long time, and can be printed in a manner similar to what is popularly called oilcloth. A substance called Linoleum has been proposed as a substitute for india rubber and gutta percha, and is also used as a floor covering. It is produced by combining with linseed oil substances that have the property of turning it into a kind of resin or gum.

Farriery.

Notwithstanding the superseding of horses in the present day by railways as regards the accomplishment of long journeys, the number of them which is employed in connection with carts, waggons, carriages, cabs, omnibuses and tramcars, and other purposes, is prodigious. The work of the farrier, who has greatly to do with them, therefore still forms a large item in the business of a country. A farrier may be regarded as a blacksmith, a shoer of horses, and a veterinary surgeon. He gets his name from *ferrum*, iron, because he works in that metal. His principal business consists of shoeing. The treatment of the diseases of horses is more generally attended to by a class of trained practitioners called veterinarians, who also in some cases carry on the shoeing business.

Tobacco Manufacture.

Although tobacco is not one of the prime necessities of mankind, like food, clothing, or a dwelling, and the manufacture of it is not productive like agriculture, shipbuilding, or the construction of engines and machinery; yet, on account of the vast quantity of the commodity which is consumed, and the large number of persons employed in the preparation of it, its manufacture is a form of industry of considerable importance. We may be permitted to remark, that viewed sentimentally, there is some suitableness in our making tobacco the last subject of which we shall treat. Though many operatives smoke tobacco while they are engaged at their work, and many active and shrewd men indulge in a pipe or cigar when transacting their daily business, there are others who regard smoking more as a pastime and solace to be enjoyed when their labours are over for a time, so we here finish our task with tobacco. Tobacco is the leaf of the *Nicotania Tabacum*, a tropical herbaceous plant with a strong erect stem. It grows to the height of six or eight feet, with a fine handsome foliage. Virginia, in the United States of America, forms the centre of the chief tobacco growing districts. The largest leaves of the plant are about twenty inches long and five broad. When the leaves are ripe, they are cut from the plant and are dried or cured in barns. Tobacco is imported in two forms known as "strip leaf" and "handwork," the former being that in which the central rib has been stripped from the leaf, and the latter being the leaf and stem together. In the process of manufacture a great number of leaves are pressed together into a compact cake, and the mass is shredded very fine by an ingenious cutting-machine. "Birds'-eye" has little pieces of stem shredded with the leaf; "Returns" is made from the brightest-coloured leaves; "Shag" is made from the darkest leaves much sprinkled with water; "Pigtail," which is used for chewing, is twisted in small rolls by means of a kind of spinning-wheel; "Cavendish" is tobacco made up into cakes. "Cigars" are formed by rolling a portion of a sound leaf round pieces of other leaves; "Snuff" is tobacco ground. Fancy snuffs are scented. As showing the great extent of the tobacco trade, we may state that the quantity retained in the United Kingdom in the year 1880, was more than 48,261,000 lbs.

Conclusion.

Having now reviewed all the great manufactures of the world, and many of the lesser yet still important departments of human industry, we cannot refrain from making at least one general remak in conclusion, which is, that ceaseless activity and continual progress are observable in every field of labour in which men are engaged. What a recent writer has said about what capital has accomplished in modern times, may be affirmed with equal truth respecting industry, without which capital is impotent and unproductive. "It has," he says, "made railways, docks, harbours, tramway, and telegraphic communication all over the world. It has opened some of the richest mining districts of the earth, has peopled deserts, and converted savage wilds into fruitful regions." Such are some of the results which have been produced on a large scale in recent times by The Industries of the World.

THE END.

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